FLORIDA KEYS CARRYING CAPACITY

ANCILLARY INVESTIGATIONS IN SUPPORT OF THE DEVELOPMENT OF THE INTEGRATED WATER MODULE

August 2002

Third Revision

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1.0   BACKGROUND AND OBJECTIVES

1.1   Background

This report describes the results of the data acquisition and assessment activities and subsequent formulation/reformulation of the components of the Integrated Water Module of the Conceptual/Draft Carrying Capacity Analysis Model (CCAM) for the Florida Keys Carrying Capacity Study (FKCCS). The development of the Integrated Water Module's components also considers the observations, comments and recommendations provided by invited experts and the public during the Technical Wrap-Up Workshop held on January 9 and 10, 2001. The report also includes recommended studies and activities needed to complete the Integrated Water Module for full incorporation into the test version of the CCAM.

1.2   Objectives of this Delivery Order

The Integrated Water Module is responsible for calculating pollutant loads in the nearshore waters in the Study Area, based on land use and policy decisions, for subsequent use in the Marine Environment Module. Individual components of the Water Module run within the Geographic Information Systems (GIS) modeling environment, utilizing both temporal and spatial data.

The goal of Delivery Order (DO) 8 is to acquire, review and evaluate available relevant information sources and then complete the formulation of the individual components of the Integrated Water Module. Specific objectives of this effort include:

- Acquire and review recent regional plans for wastewater and stormwater management;

- Acquire and review existing data relating to the physical and hydrologic characteristics of the islands;

- Define and develop internal computational algorithms required within the individual components;

- Develop the necessary datasets, within the limitations of available existing data, that will be required by the computational algorithms for inclusion in the CCAM's databases;

- Define the process that will be used to test the Integrated Water Module components of the CCAM;

- Identify existing calibration data that can be used to test the model;

- Summarize supplemental data collection/development needs that are required by the Integrated Water Module for final development and testing; and

- Make recommendation for subsequent testing of the Integrated Water Module components once they are integrated into the CCAM.

2.0   INTEGRATED WATER MODULE OVERVIEW

2.1   Module Functions

The Integrated Water Module is responsible for calculating pollutant concentrations and loads entering the nearshore and offshore waters in the Study Area based upon land use and policy decisions. Individual components of the Integrated Water Module run within the Geographic Information Systems (GIS) modeling environment, utilizing both temporal and spatial data. The initial formulation of the Integrated Water Module, as previously presented in Delivery Order (DO) 5, has been changed to better represent the physical conditions and processes occurring in the Study Area based upon the following:

- Results of the ancillary investigations (as provided for in the DO 8 scope of work) into the available data, regulatory processes, physical systems and related concerns of the citizens and governmental officials of the communities of the Florida Keys;

- Comments, suggestions and related directions received from the Government Study Team—particularly comments made on the DO 5 Report—and the numerous forms of input received from the Government's technical experts;

- Review comments, advice and oversight suggestions provided by the National Academy of Sciences review panel; and

- Technical expertise, related project experiences, and the best professional judgments of the Contractor's project team.

These inputs, recommendations, data acquisition/assessment activities have resulted in significant reformulations of many of the components of the Integrated Water Module. The current version of the Integrated Water Module, described in extensive detail in Section 3.0 of this report, is designed to better utilize the available data within the Florida Keys to develop, within the budget and schedule established by the Government, the best possible prediction of pollutant loadings for use in the Marine Environment Module.

2.2   Definition of Water Module Components

The Integrated Water Module includes nine individual components that address each of the following processes that define pollutant generation, conversion and transport:

- *Weather Characteristics:* The Weather Component provides the precipitation, antecedent conditions and wetfall/dryfall pollutant loading values that are used in the stormwater, Immediate Nearshore Waters and Circulation Components to generate the weather-based input flows and pollutant loads.

- *Potable Water Demand:* This component utilizes permanent and seasonal populations, and documented local water consumption to estimate potable water demands and to assess the adequacy of the existing potable water supply and primary distribution system.

- *Stormwater:* This component utilizes land use from the contributing drainage areas and associated pollutant loading rates to estimate pollutant loads being generated within each watershed, computes pollutant load reductions attributable to stormwater best management practices (BMPs), and calculates the net pollutant loads discharged to the receiving surface water and groundwater systems.

- *Wastewater:* This component utilizes permanent and seasonal populations, local wastewater generation rates, local wastewater characteristics and point source discharge data from the contributing wastesheds to estimate pollutant loads generated within each wasteshed, calculate the levels of load reduction attributable to treatment systems, and calculate the net pollutant loads of the effluent discharged to the receiving groundwater systems.

- *Groundwater:* This component simulates groundwater system interactions, including movement of flow and pollutant loads in the subsurface environment underlying each of the modeled islands in the Florida Keys and estimates groundwater discharges to the immediate nearshore waters.

- *Disposal Wells:* This component simulates injection zone interactions, including both shallow and deep well injection of effluents into the groundwater systems underlying each of the modeled islands in the Florida Keys and estimates discharges to the immediate nearshore waters.

- *Boating Discharges:* This component utilizes permanent and seasonal estimates of boating populations and loading rate data from existing studies to estimate pollutant loads discharged to the marine waters.

- *Immediate Nearshore Waters Interactions:* This component simulates concentrations occurring in the immediate nearshore waters resulting from the various pollutant sources discharged to the immediate nearshore waters, including stormwater runoff, groundwater discharges, wastewater effluent discharges, boating discharges, atmospheric loading and injection zone discharges. (Note: For the purposes of this report, the immediate nearshore waters is defined as that portion of the Nearshore Waters that are within an off-set zone of 100 meters from the shoreline.

- *Circulation Characteristics:* This component estimates net circulation vectors for the marine waters within the Study Area as required by the transport model of the Marine Environment Module.

All of these components, with the exception of the Weather Component, utilize computational algorithms that were being developed for specific conditions within the Florida Keys. Figure 1 illustrates the relationship of these elements and their process-based connectivity.

FIGURE 1
RELATIONSHIPS BETWEEN THE NINE COMPONENTS
OF THE INTEGRATED WATER MODULE
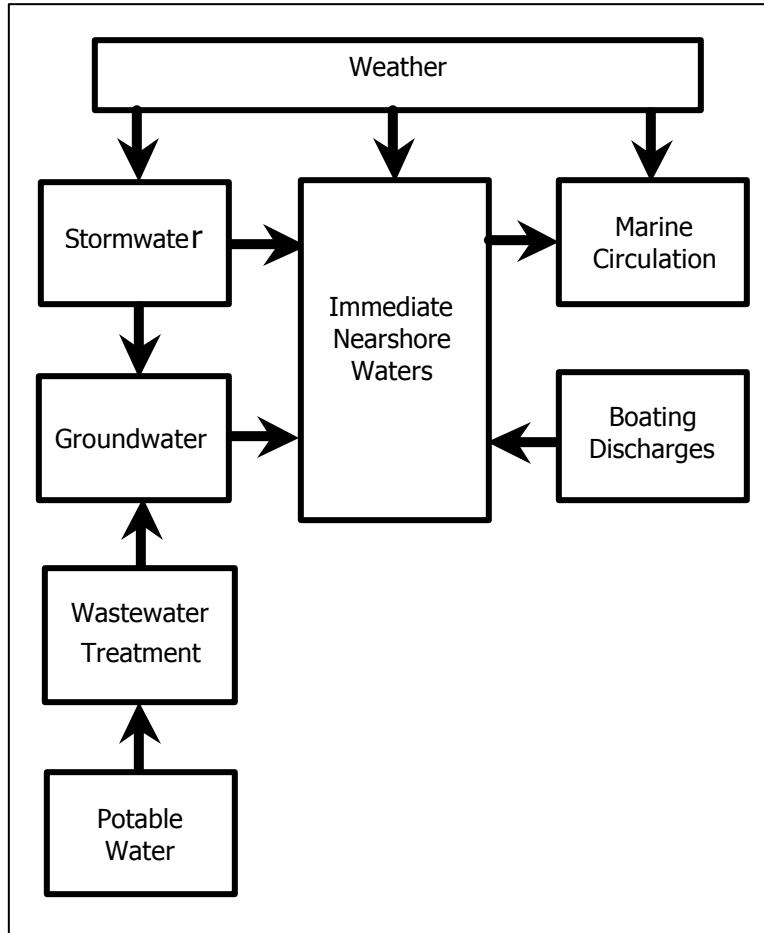
Wherever possible, the algorithm used has been developed and generally accepted in other modeling studies, and subsequently modified for use in the Conceptual/Draft Carrying Capacity Analysis Model (CCAM) through the selection and/or development of suitable input variables, input constants and management variables. In many cases, the output variables from one module constitute the input variable to another module.

2.3   Interactions with CCAM Components

The Integrated Water Module does not operate as a stand-alone model, but relies upon and interacts with other components of the CCAM as generally indicated in Figure 2. Some of the CCAM components provide inputs to the Integrated Water Module, and are figuratively "upstream" in the computation process. Other CCAM components receive inputs from the Integrated Water Module, and are figuratively "downstream" in the computation process.

FIGURE 2
RELATIONSHIPS BETWEEN THE INTEGRATED
WATER MODULE AND OTHER CCAM MODULES

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│  │         Graphical User Interface                │    │
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│  │ Land Use │  │Environmental│             │             │
│  │ Decisions│  │ Management  │             │             │
│   ╲────────╱   │ Decisions  │              │             │
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│  │ Land Use │         │            │   Marine     │      │
│  │ Module   │         ▼            │ Environment  │      │
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│        │         │Integrated│      └──────────────┘      │
│        ▼         │  Water   │                            │
│  ┌──────────┐    │ Module   │      ┌──────────────┐      │
│  │Temporary │    │          │  ──▶ │   Fiscal     │      │
│  │Land Use  │──▶ │          │      │   Impacts    │      │
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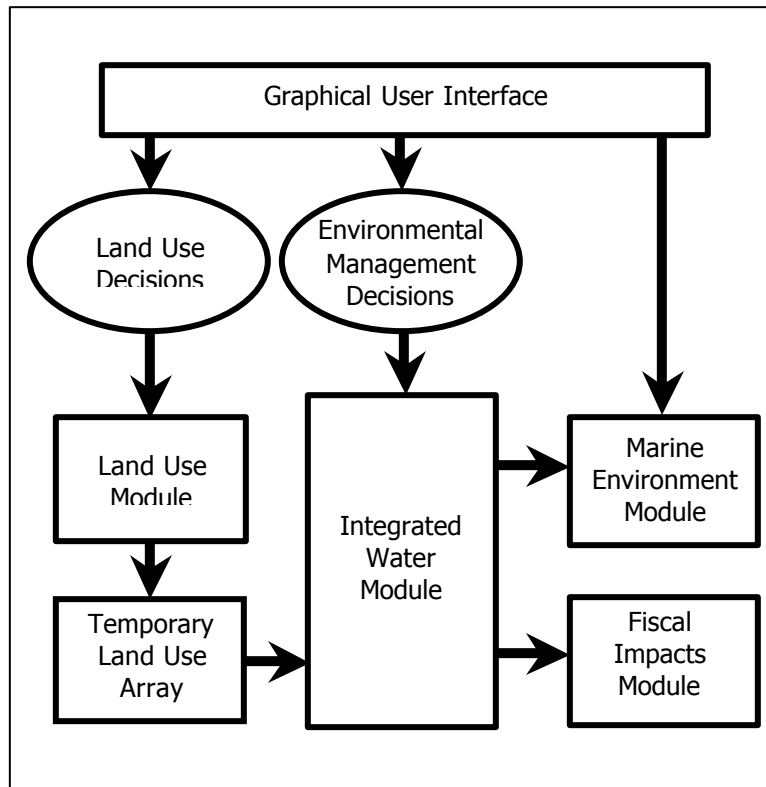
2.3.1   <u>Upstream Components of CCAM</u>

The Integrated Water Module relies upon three upstream components for the basic input information required to conduct its internal operations:

- *Scenario Decisions:* The decisions in each scenario related to the process constants that are used in each of the Integrated Water Module's components that relate to pollutant characteristics, management strategies, intervention concepts, and timing considerations. The scenario decisions are either pre-selected in a "standard" scenario, or user selected for a "custom" scenario that was input through the graphical user interface.

- *Background Data:* Temporal and spatial datasets contained in the CCAM Database that are used by the components of the Integrated Water Module to generate intra-component outputs as well as the outputs required by other CCAM modules.

- *Parcel Attribute Arrays:* Temporary output arrays from the Land Use Module that provide parcel based information regarding parcel size and location, land use, wastewater equivalent development units (EDUs) and treatment/disposal methods, stormwater BMPs, and similar parcel based data which is required by the Integrated Water Module's components.

Given these decisions and data, the Integrated Water Module generates the output process reporting and provides the inputs required for the downstream modules of the CCAM.

2.3.2   Downstream Components of CCAM

The Integrated Water Module is currently formulated to provide pollutant loading information and discharged flows to the Marine Environment Module for its use in assessing water quality impacts in the immediate nearshore waters and nearshore waters within the FKCCS Study Area.

Under discussion in DO 11 is the refinement of the Potable Water, Stormwater, and Wastewater components to provide annual operating cost and capital investment data for use in the Fiscal Impacts Module.

2.4   Conservative Module Formulation

The reformulated Integrated Water Module incorporates a conservative modeling approach that utilizes the following guidelines:

- *Assumption of Worst Pollutant Form:* In cases of Total Nitrogen (TN) and Total Phosphorous (TP) pollutant loads, where data does not exist on the speciation of the total loads, it has been assumed that the entire pollutant mass is in the soluble form which is most readily transported with the flows from stormwater runoff components and the wastewater discharges from on-site systems and disposal wells.

- *Use of Central Values:* In cases where a range of values have been reported in studies or otherwise used in regulatory processes, the value selected for use in the Integrated Water Module will be the value in the middle or the normal range of values.

- *Conservative Pollutant Characteristics:* Pollutants that are being evaluated in the Integrated Water Module are assumed to be conservative in the sense that they are neutral buoyant and well mixed, do not settle out of suspension, are non-reactive with other soluble constituents in the flow process, and do not volatilize to the atmosphere.

- *No Sediment/Benthos Interactions:* The liquid volumes involved in the transport process do not allow re-entrainment of settled solids, do not interact with the sediments or benthos to allow re-solution of settled forms of pollutants, and do not otherwise allow stripping/de-adsorption of constituents that have been removed by passing through the limestone matrix underlying the Florida Keys.

- *Assumption of No Treatment:* In the case of pollutant movement through the unsaturated and saturated subsurface limestone matrix that underlies the Florida Keys, where no treatment or pollutant removal rate has been documented in the literature for any of the pollutants of interest (except phosphorous), the Integrated Water Module assumes that no reduction of the pollutant load occurs.

These concepts are used in the formulation of the individual components of the Integrated Water Module. In many cases, the treatment process has been simply modeled with loading and treatment values selected for the input constants of the different components that reflect the preceding conservative approach.

This approach of using conservative assumptions has been adopted in the absence of suitable data in order to meet the overall objectives of flexibility in the CCAM. By incorporating the basic process component algorithm, the CCAM is capable of being modified by simply modifying the input constants when acceptable data is either developed or identified at a later date.

2.5 Time Scale and Model Units

The issue of time scale is composed of three distinct considerations that are established by the requirements of the CCAM modules that are "downstream" of the Integrated Water Module:

- *Window of Simulation:* Generally defined in terms of when in the annual cycle that the simulation takes place. An example would be a representative period during the height of the summer tourist season coincidentally occurring during the hydrologic wet season, say sometime in the month of July.
- *Simulation Period:* Generally defined as the continuous time period for which CCAM simulates responses. An example would be a 3-day period during a neap tide when marine circulation is minimal.
- *Simulation Time Step:* Defined as a fixed, constant incremental length of time that is used to segment the simulation period. An example would be a time step of four hours that would be beneficial in determining durations of lethal toxicity in the immediate nearshore waters.

Collectively, these three example time scale considerations define a specific CCAM simulation requirement that could result in 12 time steps that use data from the month of July to assess comparative potential impacts.

The Integrated Water Module uses the units that are most commonly used in the planning and regulatory areas of practice, and these are a mix of System International and English units (Table 1). Generally speaking, the following units are used:

TABLE 1
CUSTOMARY UNITS USED IN THE INTEGRATED WATER MODULE

Consideration	Type of Unit	Unit Used
Pollutant Load	English	pounds (lbs.)
Concentration	System International	milligrams/liter (mg/l) or micrograms/liter (ug/l)
Distance	English	feet (ft.) or miles (mi.)
Area	English	square yards (yd^2) or acres (ac.)
Rainfall Depth	English	inches (in.)
Flow Rates	English	million gallons per day (mgd)
Time	NA	minutes, hours, days
Volumes	English	gallons (gal.) or millions of gallons per day (mgd)

Conversion factors between System International and English units are well established and will be used in the algorithms for the different components of the Integrated Water Module as appropriate.

2.6   Water Balance Techniques

A water balance was not developed for the Florida Keys due to the lack of data for key components and a lack of consistent data sets for other components. The review of available literature for the Keys provides extensive information for certain Water Components, which are related to ongoing, funded research activities. However, sufficient data do not exist to produce a complete or meaningful water balance that is technically defensible.

Wherever possible, water balance techniques are being used within specific components of the Integrated Water Module to track water flows. Specific areas in which insufficient data exist to establish water balance components include evapo-transpiration, changes in groundwater storage, and measured groundwater discharges to marine waters.

No incremental storage of groundwaters has been adopted as an enabling assumption in the formulation of the Groundwater Component based upon available literature regarding subsurface conditions in the Keys. Water balance techniques, combined with the foregoing steady-state assumptions, were utilized to calculate groundwater flow quantities.

3.0   ANCILLARY INVESTIGATIONS AND COMPONENT REFINEMENT

This section provides a summary of each of the components that comprise the Integrated Water Module in a fixed presentation structure that includes the following elements:

- Ancillary investigations undertaken to identify and acquire available data.
- Summary of the resulting pertinent data that was gleaned from the ancillary investigation.
- Revised component formulation resulting from the ancillary investigation, comments received at the Development Order (DO) 5 Wrap-Up Technical Workshop and the NAS review panel, as well as input received from the Government Study Team and their experts.
- Enabling assumptions that were used in the formulation of the component.
- Current computational algorithms that will eventually be incorporated in the Carrying Capacity Analysis Model (CCAM).
- Definition of datasets that were developed as a result of the ancillary investigations.
- CCAM integration considerations (where appropriate).
- These discussions provide the background and basis for each of the components and its interaction with other Integrated Water Module components, as well as other modules.

3.1   Weather Component

Selected weather data characteristics are required by three other components (Stormwater, Immediate Nearshore Waters, and Circulation) to estimate pollutant loads and assess pollutant transport within the Florida Keys. The weather component processes the existing weather data passed from the GIS environment, and generates the essential parametric data used for calculating atmospheric loads, driving the circulation model, and determining three sets of inter-component flux rates (surface water to groundwater, surface water to immediate nearshore waters, and groundwater to immediate nearshore waters).

Potential weather data that was previously identified included rainfall, evapo-transpiration rate, and atmospheric loading rates for the pollutants of concern.

3.1.1   Ancillary Investigation Activities

Several data sources were consulted, including the South Florida Water Management District (SFWMD), the National Oceanic and Atmospheric Administration (NOAA), EarthInfo Inc., the U.S. Geological Survey (USGS), and the University of Florida's Institute of Food and Agricultural Sciences (IFAS). Internet and library searches were also conducted to help identify any other data sources that could be used.

South Florida Water Management District

SFWMD has been monitoring and collecting historical weather and rainfall data for over 40 years. SFWMD hydrological database contains data from the District's monitoring stations and NOAA weather stations. Rainfall data from 14 weather stations in the Florida Keys were obtained and these are summarized in Section 3.1.2.

A review of the SFWMD listing of technical publications did not reveal any published weather investigations of the Florida Keys, but it did reveal five technical papers on atmospheric deposition of phosphorous in South Florida:

- Ahn, H., 1998. *Statistical Modeling of Total Phosphorous Concentrations Measured in South Florida Rainfall*. Technical Publication WRE-358;

- Ahn, H., 1998. *Outlier Detection in Total Phosphorous Concentration Data from South Florida Rainfall*. Technical Publication WRE-359;

- Ahn, H. and R.T. James, 1998. *Outlier Detection in Dry Deposition Phosphorous Rates Measured from South Florida Rainfall*. Technical Publication WRE-365;

- Ahn, H. and R.T. James, 1998. S*tatistical Modeling of Dry Deposition Phosphorous Rates Measured from South Florida*. Technical Publication WRE-366; and

- Ahn, H. and R.T. James, 1999. *Variability, Uncertainty, and Sensitivity of Phosphorous Deposition Load Estimates in South Florida*. Technical Publication WRE-374.

National Oceanic and Atmospheric Administration

The National Climatic Data Center (NCDC) archives 99 percent of all NOAA data. With over 100 years of weather observations, the NCDC has generated a historical database of climate data. Most of NOAA's rainfall data in the Florida Keys were obtained through SFWMD. Rainfall data for a station in Duck Key were obtained from NCDC to supplement SFWMD's data. Since evaporation data from the Florida Keys were not found, evaporation data from the Flamingo station in the southern Everglades were obtained.

An abstract of a technical paper on atmospheric deposition, *Atmospheric Deposition of Nitrogen and Phosphorous to the South Florida Bay Ecosystems* by Pai-Yei Whung, was obtained and renewed. The abstract summarized dry and wet deposition samples collected at a meteorological tower at the Keys Marine Laboratory at Long Key.

EarthInfo Inc.

EarthInfo compiled NCDC Hourly Precipitation (on CD-ROM) contains precipitation data in the TD-3240 files of the NCDC. Data received from NCDC along with indexes and summary tables are published in regional CDs. Rainfall data from three weather stations in the Florida Keys were obtained and are summarized in Section 3.1.2.

U.S. Geological Survey

The South Florida Information Access (SOFIA) website was established to enable the USGS to share its scientific information with resource managers in South Florida. A technical paper, *Regional Evaluation of Evapotranspiration in the Everglades* by Edward German was downloaded from this website. This technical paper evaluates a network of nine sites that provides evapo-transpiration and related meteorological data at locations in the Everglades.

University of Florida's Institute of Food and Agricultural Sciences

IFAS develops data through monitoring and research on agricultural and natural resources all over Florida. IFAS's fact sheet AE-251, *Using Reference Evapotranspiration Data* by G. Clark and C. Stanley presents a table with estimated average daily reference evapo-transpiration data for the three different regions in the State of Florida. The data source of this table includes the University of Florida, Cooperative Extension Service Bulletin 205, *Potential Evapotranspiration Probabilities and Distributions in Florida*.

3.1.2   Resulting Data

Rainfall Data

Rainfall data from fourteen rainfall stations were collected for review. Ten of the stations had sufficient period of record to characterize historical rainfall. Table 2 summarizes the rainfall stations collected, their source and their period of record. The average interval between rainfall events is not used in the CCAM and has not been included in Table 2.

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TABLE 2
RAINFALL STATIONS

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Station Name	Station ID	Source	Period of Record	
Big Pine Key	06209	SFWMD	5/1/50	11/30/55
Duck Key	82441	NOAA	11/1/82	11/30/00
Key West WSO Airport	4570	EarthInfo	8/1/48	12/31/96
Key West	4575	EarthInfo	1/1/42	7/31/58
Key West	06162	SFWMD	1/1/01	2/28/74
Key West W. WSO Airport	06163	SFWMD	1/1/70	11/30/98
Key West WSO Airport	06245	SFWMD	1/1/41	7/31/91
Lignumvitae Key	5035	EarthInfo	1/1/42	10/31/76
Lignumvitae Key	06246	SFWMD	1/1/42	12/31/72
Long Key	06217	SFWMD	5/1/16	11/30/35
Marathon Shores	06164	SFWMD	5/1/50	10/31/75
Sand Key	06402	SFWMD	1/1/14	12/31/24
Tavernier	06165	SFWMD	6/1/36	10/30/98
TPTS	15658	SFWMD	11/22/91	3/27/01

Evaporation Data

Daily evaporation data from NOAA's Flamingo Ranger Station in the southern Everglades were collected with a period of record from June 1962 to October 1975. Evaporation data from this station, the closest station to the Keys, were collected since evaporation or evapo-transpiration data in the Florida Keys were not found. A table of estimated average daily reference evapo-transpiration data for south, central, and north Florida regions were collected from IFAS Fact Sheet (AE-251).

Atmospheric Deposition Data

Both dry and wet atmospheric depositions were sampled for nitrogen and phosphorous at a meteorological station at the Florida Keys Marine Laboratory at Long Key. An abstract of a technical paper titled *Atmospheric Deposition of Nitrogen and Phosphorous to the South Florida Bay Ecosystems* presented a summary of average values for the period of October 1998 to February 1999. Efforts made to contact NOAA's principal investigators were unsuccessful.

The Marine Laboratory at Long Key was contacted and, based on conversations with the laboratory staff; it appears that data is no longer being collected. It is unknown if additional data beyond the summary of the five month period presented in the abstract is available.

SFWMD has been collecting atmospheric deposition data in South Florida since 1974, but no data collected in the Florida Keys were found. Atmospheric deposition of phosphorous data collected in the Everglades area was obtained from selected reports. It is unlikely that phosphorous data from the Everglades would be similar to that in the Keys, due to the effect of regional agriculture on the Everglades. Such activities are not present in the Keys.

3.1.3 Revised Component Formulation

The previous identification of output variables for the Weather Component was based on a conceptual approach and assumed that all possible data existed. In the pursuit of available data, it was found that a number of different variables could not be addressed given the proposed time scale and the lack of sufficient or adequate data to describe and characterize the variable. In addition, the initial concept of this component was to compute weather data for each simulation time step within CCAM. The current component formulation includes the provision for pre-processing the weather data and storing the necessary parametric data in look-up tables for use by the other components. These tables can be updated or added to later. In this manner, the Weather Component will not be required to interactively compute parametric data for each time step in the simulation which will shorten the total CCAM run times for each simulated scenario.

Input Variables

- $[t]$ = Integer value (1-13) indicating the desired time period for which weather data is desired. A t value of 1-12 indicates a month (Jan-Feb), while a t value of 13 indicates annual.

- $[pu]$ = The wastewater planning unit (island) for which weather data is desired.

Input Constants

- PRECIPAVG [*t, pu*] = The average rainfall in decimal inches for period (*t*) at wastewater planning unit (*pu*).

- PRECIPWET [*t, pu*] = The wet period (90-percentile) rainfall in decimal inches for period (*t*) at wastewater planning unit (*pu*). Rainfall for period (*t*) will exceed this value no more than 10 percent of the time.

- PRECIPDRY [*t, pu*] = The dry period (10-percentile) rainfall in decimal inches for period (*t*) at wastewater planning unit (*pu*). Rainfall for period (*t*) will be less than this value no more than 10 percent of the time.

- EVAPAVG [*t, pu*] = The average evaporation in decimal inches for period (*t*) at wastewater planning unit (*pu*).

- EVAPHI [*t, pu*] = The 90-percentile evaporation in decimal inches for period (*t*) at wastewater planning unit (*pu*). Evaporation will exceed this value for period (*t*) no more than 10 percent of the time.

- EVAPLO [*t, pu*] = The 10-percentile evaporation in decimal inches for period (*t*) at wastewater planning unit (*pu*). Evaporation will be less than this value for period (*t*) no more than 10 percent of the time

3.1.4   Enabling Assumptions

It was assumed that the periods of available record for the rainfall and evaporation data were adequate to accurately estimate the expected weather conditions in the Keys. In some cases, these periods were as short as ten years, which may result in non-representative averages.

3.1.5   Current Computational Algorithm

Since the Weather Component in the current formulation of the Integrated Water Module has been modified from a computational algorithm, to a series of look-up data tables that are called by other components and modules of the CCAM, the Weather Component does not require an algorithm since it performs no computations.

3.1.6   Definition of Datasets

Rainfall

A composite data set was developed for Key West from both the SFWMD and EarthInfo data to create a 92-year period of record spanning from 1901 to 1998. Rainfall data from the Sand Key and Big Pine rainfall stations were not used since their periods of record were at 11 and 6 years respectively. The period of record for the remaining ten rainfall stations ranged from 11 to 70 years with an average period of record of 38 years. The TPTS rainfall station also had a short period of record (11 years), but was included since it was the only rainfall station in the northeastern part of the Florida Keys (Key Largo).

The geographic location of each of the stations was examined to assess their distribution in relationship to the individual wastewater planning units/islands. This resulted in the selection of six stations to provide the necessary rainfall data for use in CCAM. Daily rainfall data from the selected stations were compiled and summarized into monthly and annual records.

Annual rainfall summaries were developed to determine the average, wet and dry annual rainfall. The dry and wet year values were developed by assuming a normal distribution and selecting the 10 percent and 90 percent non-exceedance annual rainfall. Table 3 summarizes the six selected rainfall stations and the annual rainfall values. Figure 3 shows this information graphically.

Monthly totals were computed for the selected stations from the daily rainfall data. A summary of rainfall by monthly total was developed to identify the average, wet and dry rainfall amounts for each month of the year. The same method used to select the wet and dry year was used to identify the wet and dry months.

TABLE 3
ANNUAL RAINFALL FOR SELECTED STATIONS

Station	ID	Source	Study Area	Period of Record (years)	Annual Rainfall (inches)		
					Avg.	Dry	Wet
Key West	RS-2	SFWMD	Key West	92	37.63	26.81	51.82
Marathon	RS-4	SFWMD	Marathon Primary	26	35.07	22.78	55.01
Long Key	RS-6	SFWMD	Long Key/Layton	20	40.50	29.47	55.17
Lignumvitae	RS-7	EarthInfo	Lower Matecumbe	35	38.25	26.56	54.06
Tavernier	RS-9	SFWMD	Tavernier PAED 15	63	41.26	25.40	59.42
TPTS	RS-10	SFWMD	PAED 21	11	43.39	26.17	64.75

FIGURE 3
ANNUAL RAINFALL
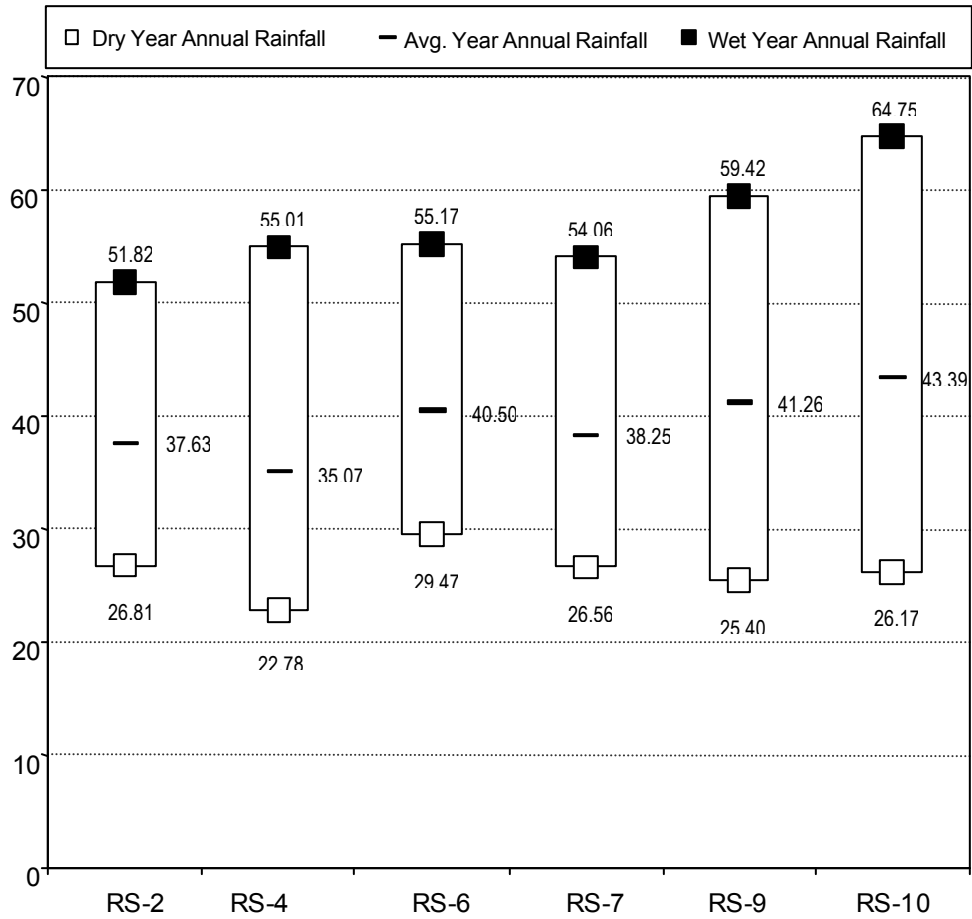
Table 4 lists the six selected rainfall stations and the monthly values for rainfall. Table 5 lists each wastewater planning unit/island and the rainfall station associated with it in the Weather Component. Figures 4 through 9 show the monthly rainfall values for each of the selected stations.

TABLE 4
MONTHLY RAINFALL DATA

Station ID	Monthly Rainfall (inches)			Monthly Rainfall (inches)			Monthly Rainfall (inches)			Monthly Rainfall (inches)		
	Avg.	Dry	Wet	Avg.	Dry	Wet	Avg.	Dry	Wet	Avg.	Dry	Wet
	January			**February**			**March**			**April**		
RS-2	0.92	0.16	4.19	0.97	0.18	3.75	0.91	0.13	3.82	1.04	0.18	4.54
RS-4	1.17	0.23	5.36	1.25	0.27	2.98	0.89	0.12	4.07	0.74	0.12	3.92
RS-6	0.93	0.22	3.91	0.87	0.25	3.10	0.90	0.14	3.33	1.39	0.38	3.75
RS-7	0.85	0.15	3.95	0.81	0.13	3.18	0.48	0.04	3.97	0.59	0.04	5.37
RS-9	1.11	0.18	3.91	1.17	0.21	3.91	1.08	0.15	4.72	1.15	0.17	5.07
RS-10	1.68	0.46	6.98	0.87	0.11	6.76	1.72	0.67	4.16	0.38	0.02	7.14
	May			**June**			**July**			**August**		
RS-2	2.10	0.43	6.34	3.36	1.00	9.44	2.86	1.09	6.80	3.99	2.01	7.68
RS-4	2.09	0.45	8.99	3.60	0.89	11.25	2.91	0.96	6.98	3.83	2.01	7.48
RS-6	2.69	0.69	7.95	2.30	0.74	5.79	3.29	1.10	7.59	5.37	2.74	9.91
RS-7	2.25	0.41	6.81	3.33	0.46	12.21	3.13	0.83	5.93	2.68	0.64	5.87
RS-9	3.00	0.94	8.47	4.71	1.43	13.54	3.40	1.32	7.68	4.40	1.96	8.64
RS-10	1.77	0.55	6.42	4.75	0.94	22.05	2.74	1.31	6.43	6.11	3.61	9.58
	September			**October**			**November**			**December**		
RS-2	5.59	3.09	10.19	4.13	1.52	10.65	1.20	0.20	5.80	1.13	0.26	4.51
RS-4	5.15	1.58	11.53	5.06	2.49	9.71	0.94	0.22	4.08	1.14	0.32	4.22
RS-6	7.17	3.45	13.03	7.14	3.43	15.36	1.32	0.30	5.81	0.57	0.06	3.53
RS-7	3.16	0.29	13.70	3.79	0.58	10.39	0.65	0.06	4.53	0.64	0.07	3.85
RS-9	6.35	3.26	12.18	5.61	2.34	12.35	1.40	0.27	5.74	1.27	0.30	4.72
RS-10	5.14	3.19	8.29	5.89	1.80	15.24	1.54	0.27	8.40	1.39	0.39	4.86

TABLE 5
RAINFALL STATION BY STUDY AREA

Study Area/Island	Study Area #	Rain Gage
Key West	0	RS-2
Stock Island	1	RS-2
Boca Chica	2	RS-2
Bay Point	3	RS-2
Lower Sugarloaf	4	RS-2
Upper Sugarloaf	5	RS-2
Cudjoe Key	6	RS-2
Summerland Key	7	RS-4
Big/Middle Torch Key	8	RS-4
Ramrod Key	9	RS-4
Little Torch Key	10	RS-4
Big Pine Key	11	RS-4
Bahia Honda Key	12	RS-4
Marathon Primary	13	RS-4
Marathon Secondary	14	RS-5
Long Key/Layton	15	RS-6
Lower Matecumbe	16	RS-7
Upper Matecumbe	17	RS-7
Windley Key	18	RS-7
Plantation Key	19	RS-9
Tavernier PAED 15	20	RS-9
Rock Harbor PAED 16	21	RS-9
PAED 17	22	RS-10
PAED 18	23	RS-10
PAED 19 and 20	24	RS-10
PAED 22	25	RS-10
PAED 21	26	RS-10
Ocean Reef Club	27	RS-10

FIGURE 4
MONTHLY RAINFALL STATION RS-2
(KEY WEST)

	Dry		Avg		Wet

Month	Dry	Avg	Wet
Jan	0.16	0.92	4.19
Feb	0.18	0.97	3.75
Mar	0.13	0.91	3.82
Apr	0.18	1.04	4.54
May	0.43	2.10	6.34
Jun	1.00	3.36	9.44
Jul	1.09	2.86	6.80
Aug	2.01	3.99	7.68
Sep	3.09	5.59	10.19
Oct	1.52	4.13	10.65
Nov	0.20	1.20	5.80
Dec	0.26	1.13	4.51

24
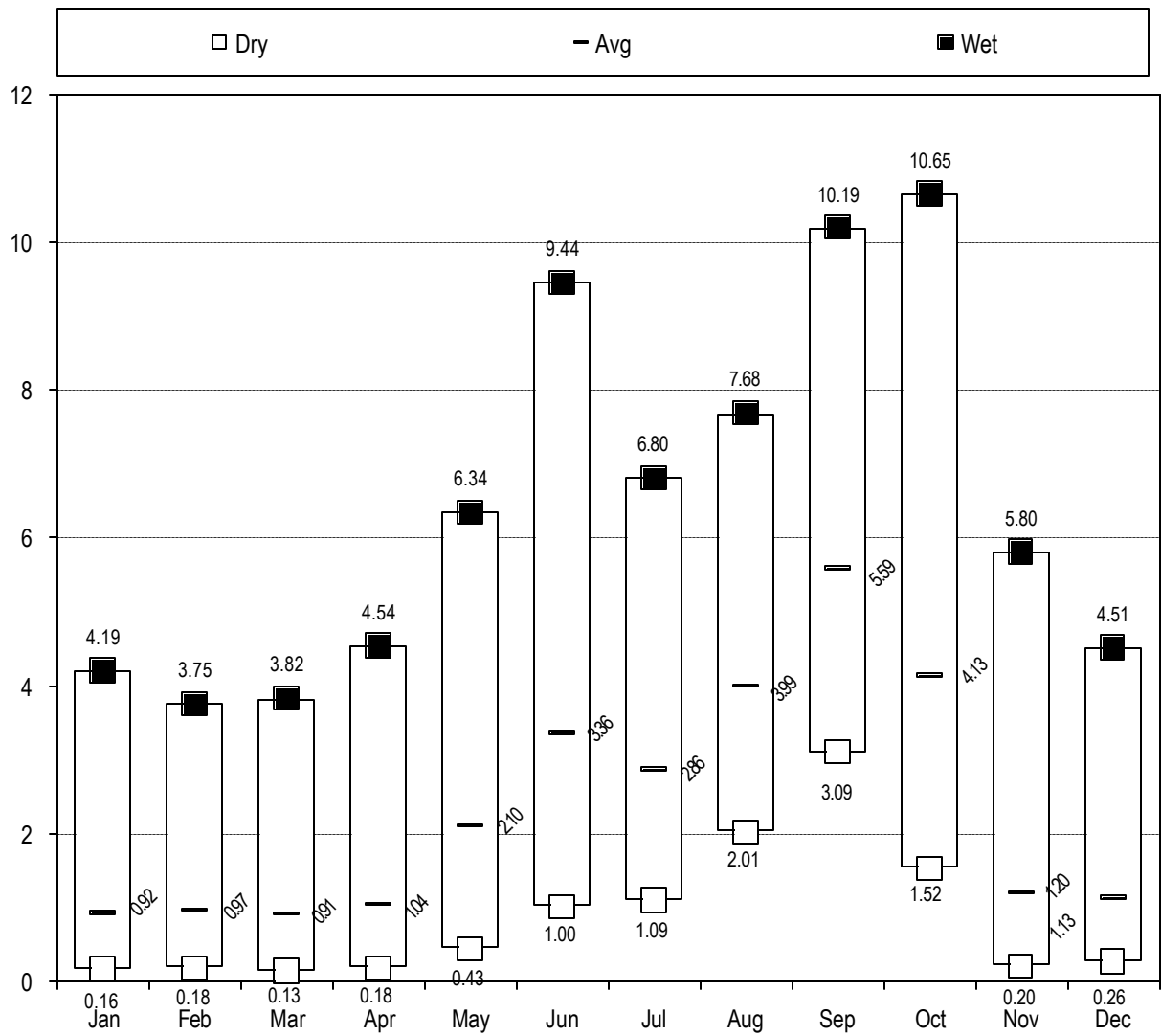
FIGURE 5
MONTHLY RAINFALL STATION RS-4
(MARATHON)
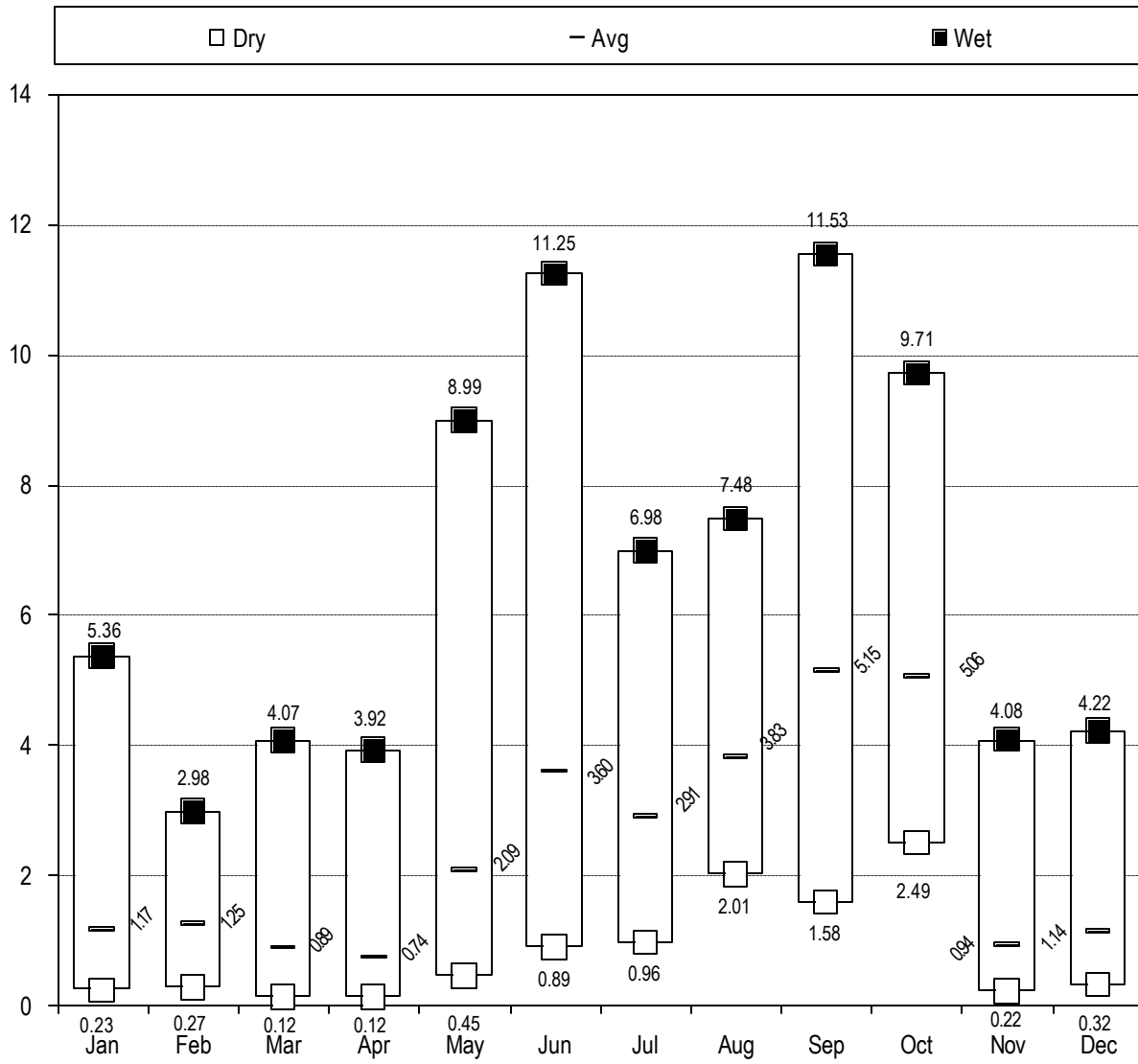
FIGURE 6
MONTHLY RAINFALL STATION RS-6
(LONG KEY)

□ Dry   ─ Avg   ■ Wet

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wet	3.91	3.10	3.33	3.75	7.95	5.79	7.59	9.91	13.03	15.36	5.81	3.53
Avg	0.93	0.87	0.90	1.39	2.68	2.30	3.29	5.37	7.17	7.14	1.32	0.57
Dry	0.22	0.25	0.14	0.38	0.69	0.74	1.10	2.74	3.45	3.43	0.30	0.06

26
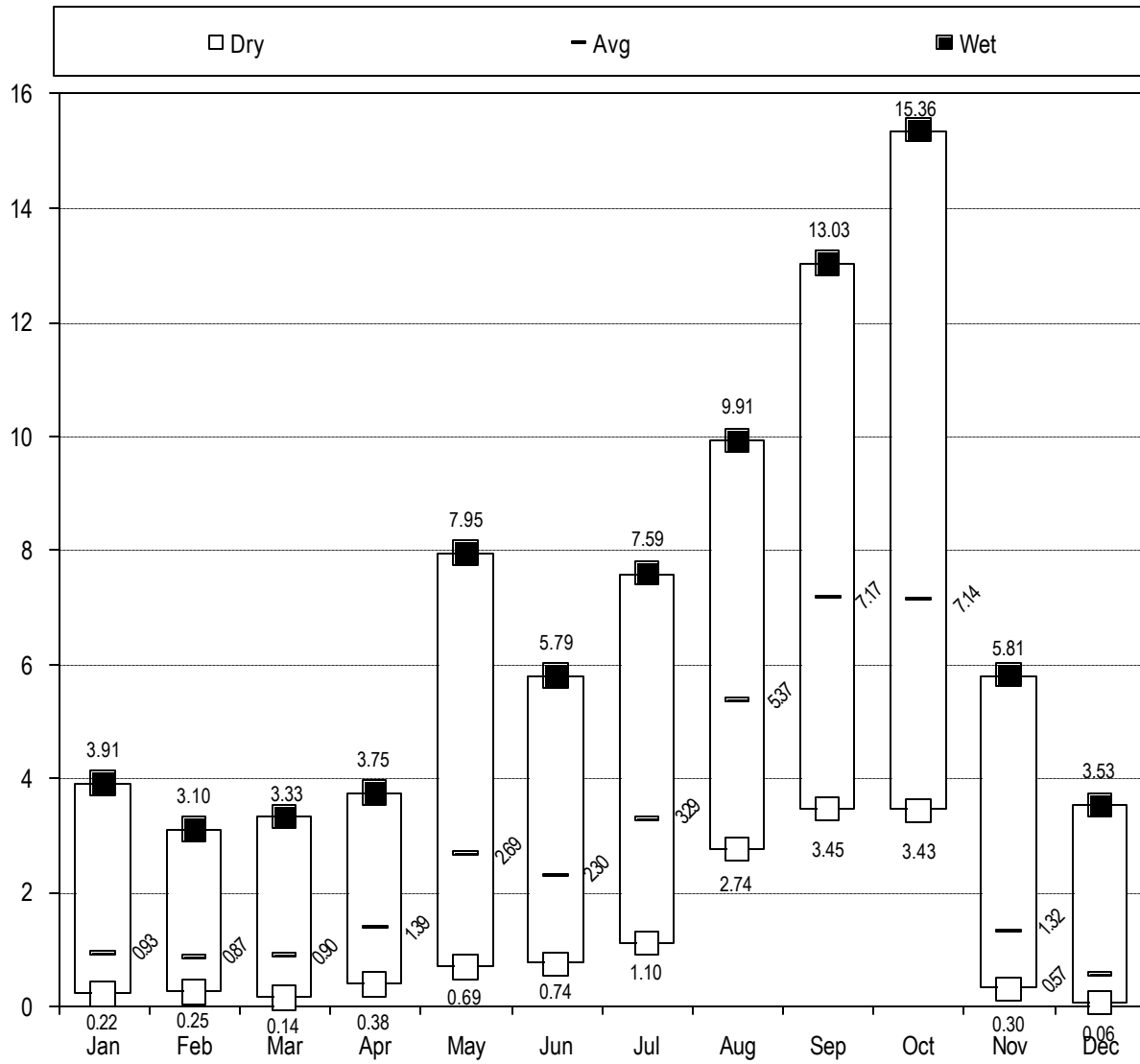
FIGURE 7
MONTHLY RAINFALL STATION RS-7
(LIGNUMVITAE)
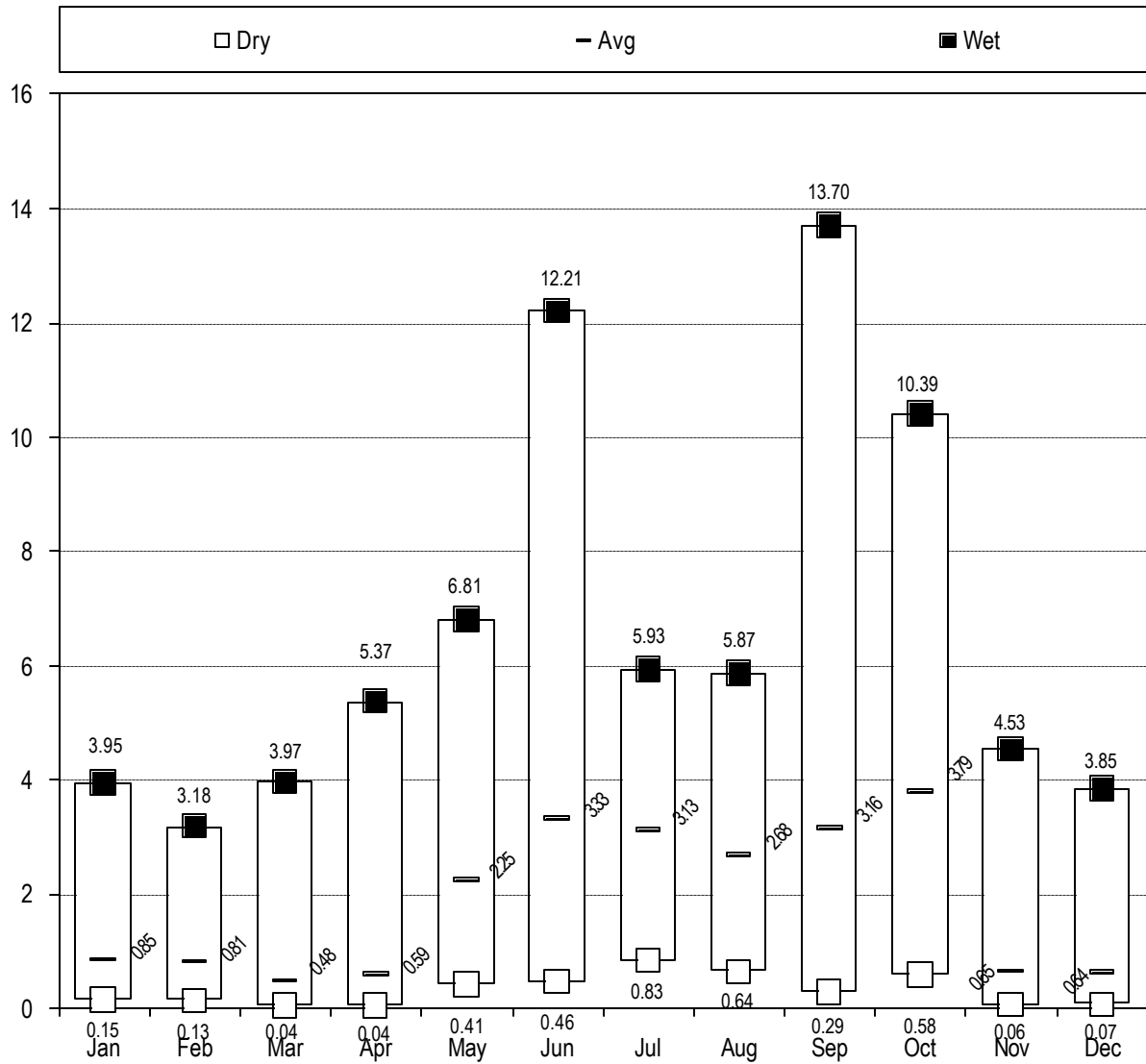
FIGURE 8
MONTHLY RAINFALL STATION RS-9
(TAVERNIER)

	Dry	Avg	Wet

Jan: 3.91, 1.11, 0.18
Feb: 3.91, 1.17, 0.21
Mar: 4.72, 1.08, 0.15
Apr: 5.07, 1.15, 0.17
May: 8.47, 3.00, 0.94
Jun: 13.54, 4.71, 1.43
Jul: 7.68, 3.40, 1.32
Aug: 8.64, 4.40, 1.96
Sep: 12.18, 6.35, 3.26
Oct: 12.35, 5.61, 2.34
Nov: 5.74, 1.40, 0.27
Dec: 4.72, 1.27, 0.30
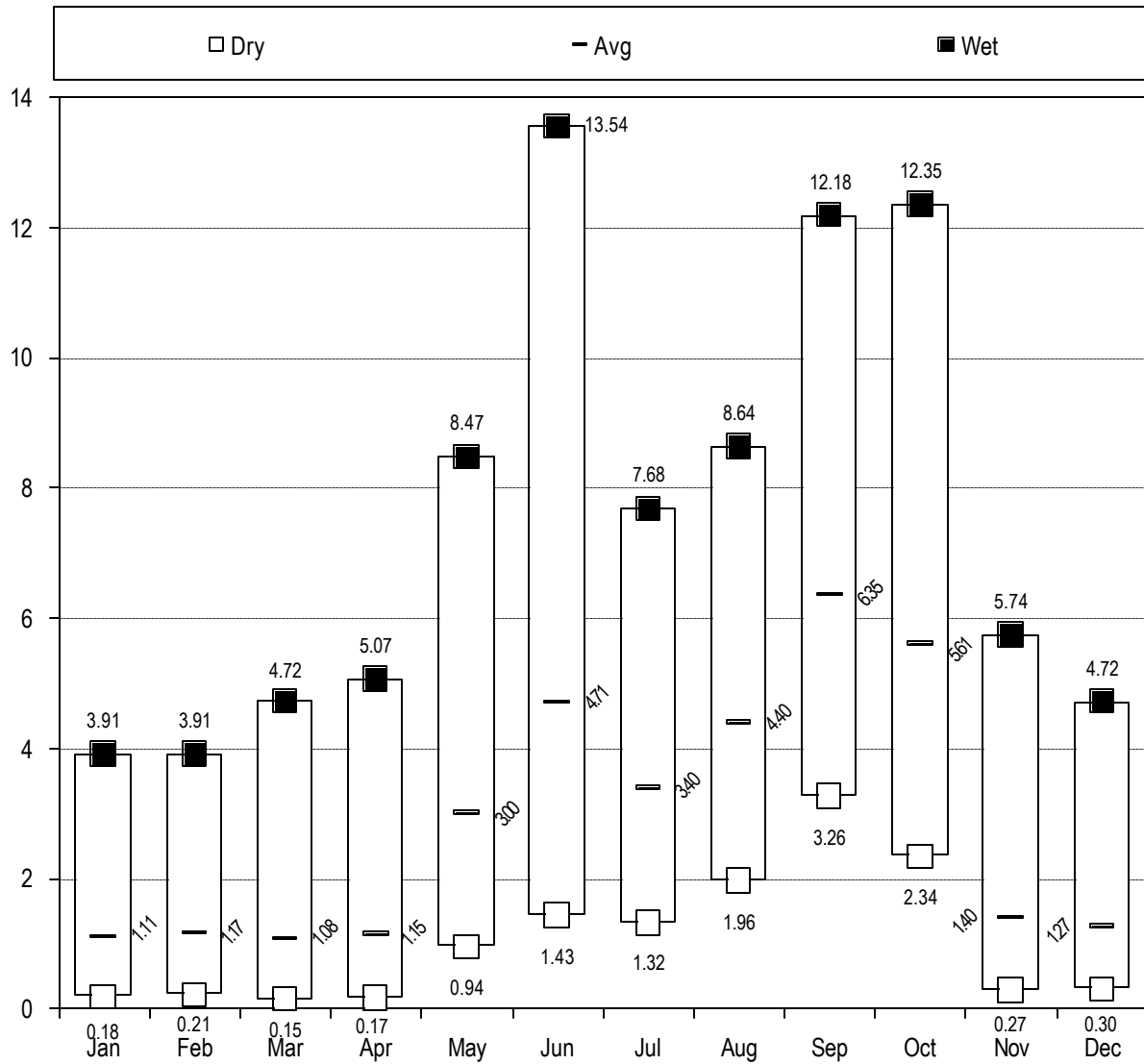
FIGURE 9
MONTHLY RAINFALL STATION RS-10
(KEY LARGO)
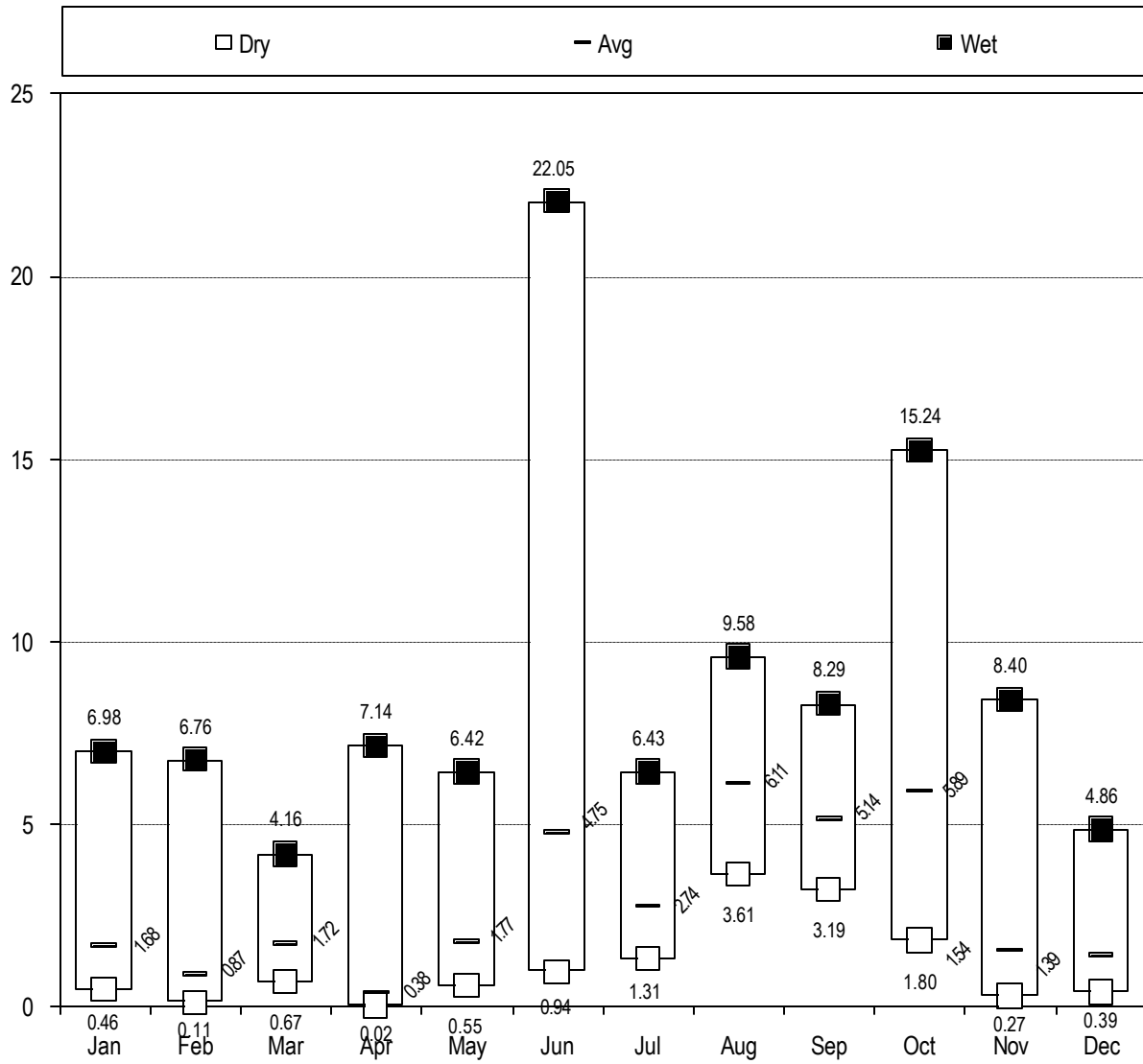
Evaporation

Evaporation is not used in the current formulation of the Integrated Water Module. Information on evaporation was collected under the auspices of an earlier formulation of the module and is presented in this report for informational purposes.

The average daily evaporation values from the NOAA station in Flamingo were used in the analysis and development of the evaporation dataset. Similar to the processing of rainfall data, the daily evaporation data was accumulated into annual and monthly values. Months that were less than 50 percent complete were removed from the data set. The remaining months were extended linearly to estimate the complete monthly values. The extrapolated data was used to develop the annual summary data. Years that were less than 50 percent complete were removed from the analysis of the average wet and dry values.

Based on this analysis, the average annual evaporation was 73.08 inches. The 10 percent non-exceedance and 90 percent non-exceedance values were computed as 62.24 and 83.91 inches, based on a normal distribution. Table 5 lists the data used to estimate the average, high and low annual evaporation values. Figure 10 shows the information in Table 6 graphically.

The monthly totals were used to develop estimates of the average, high and low evaporation values by month. Months that were less than 50 percent complete were excluded from the analysis. The 10 percent non-exceedance and 90 percent non-exceedance monthly values were estimated based on a normal distribution. Table 6 lists the data used to estimate the average, high and low monthly evaporation values. Figure 11 shows the information in Table 7 graphically.

TABLE 6
ANNUAL EVAPORATION DATA
FLAMINGO STATION

Year	Measured Evaporation (inches)	Record Days	Percent Complete	Extrapolated Evaporation (inches)
1963	60.48	257	70.4%	72.86
1964	79.79	333	91.0%	88.61
1966	72.69	295	80.8%	75.86
1967	68.52	269	73.7%	69.51
1968	58.84	285	77.9%	69.97
1969	51.80	307	84.1%	62.40
1970	65.51	329	90.1%	73.54
1971	77.00	328	89.9%	85.24
1972	55.73	247	67.5%	63.18
1973	53.70	253	69.3%	69.59

FIGURE 10
ANNUAL EVAPORATION DATA
FLAMINGO STATION
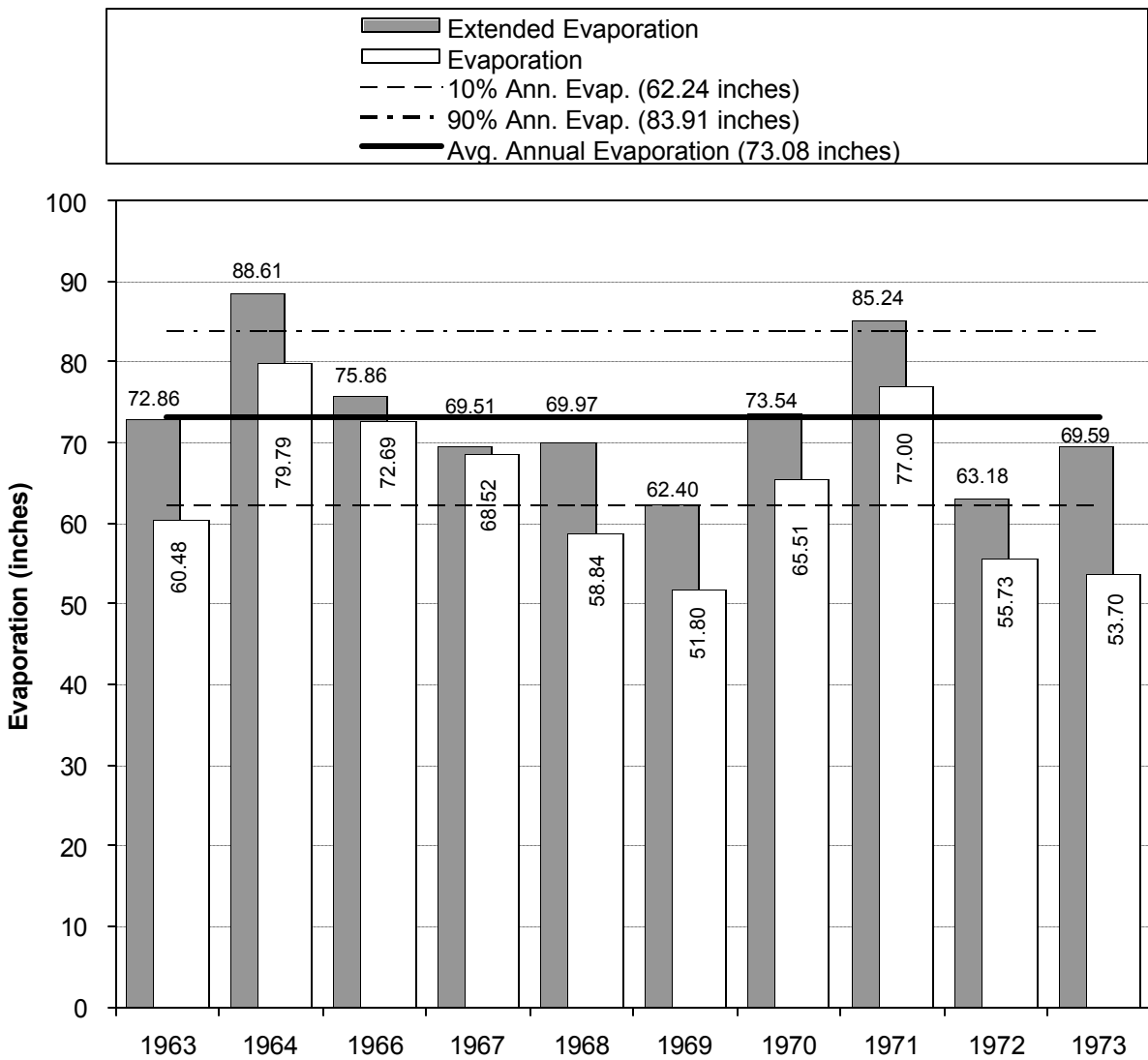
TABLE 7
MONTHLY EVAPORATION DATA
FLAMINGO STATION

	Month	10 Percent Extrapolated Evaporation	Average Evaporation	Extrapolated Average Evaporation	90 Percent Extrapolated Evaporation
1	January	3.18	4.39	4.85	6.51
2	February	4.02	4.80	5.19	6.36
3	March	6.03	6.85	7.58	9.13
4	April	7.56	7.77	8.86	10.15
5	May	8.04	8.15	9.94	11.85
6	June	6.24	6.21	7.83	9.41
7	July	6.11	7.33	8.13	10.15
8	August	6.26	6.37	7.59	8.93
9	September	4.72	5.09	6.58	8.44
10	October	4.55	5.32	5.99	7.43
11	November	3.34	4.12	4.39	5.44
12	December	3.29	3.84	4.33	5.38
	ANNUAL	62.24	64.41	73.08	83.91

Atmospheric Deposition

Very little data on aerial deposition specific to the Keys has been collected. The only relevant data identified was collected at a meteorological station at the Florida Keys Marine Laboratory at Long Key. The abstract of a technical paper, *Atmospheric Deposition of Nitrogen and Phosphorous to the South Florida Bay Ecosystems,* is currently the only information found on this data and only a brief summary of average values for the collected data over a 5-month period were presented. Table 8 shows the average deposition rate data presented in the paper.

TABLE 8
AVERAGE DEPOSITION RATE DATA
OCTOBER 1998 TO FEBRUARY 1999

Average weekly wet NH_4 deposition	0.11 mg NH_4/m^2/wk
Average weekly wet NO_3 deposition	0.71 mg NO_3/m^2/wk
Average weekly dry NH_4 deposition	0.18 mg NH_4/m^2/wk
Average weekly dry PO_4 deposition	0.10 mg PO_4/m^2/wk

FIGURE 11
MONTHLY EVAPORATION DATA
FLAMINGO STATION
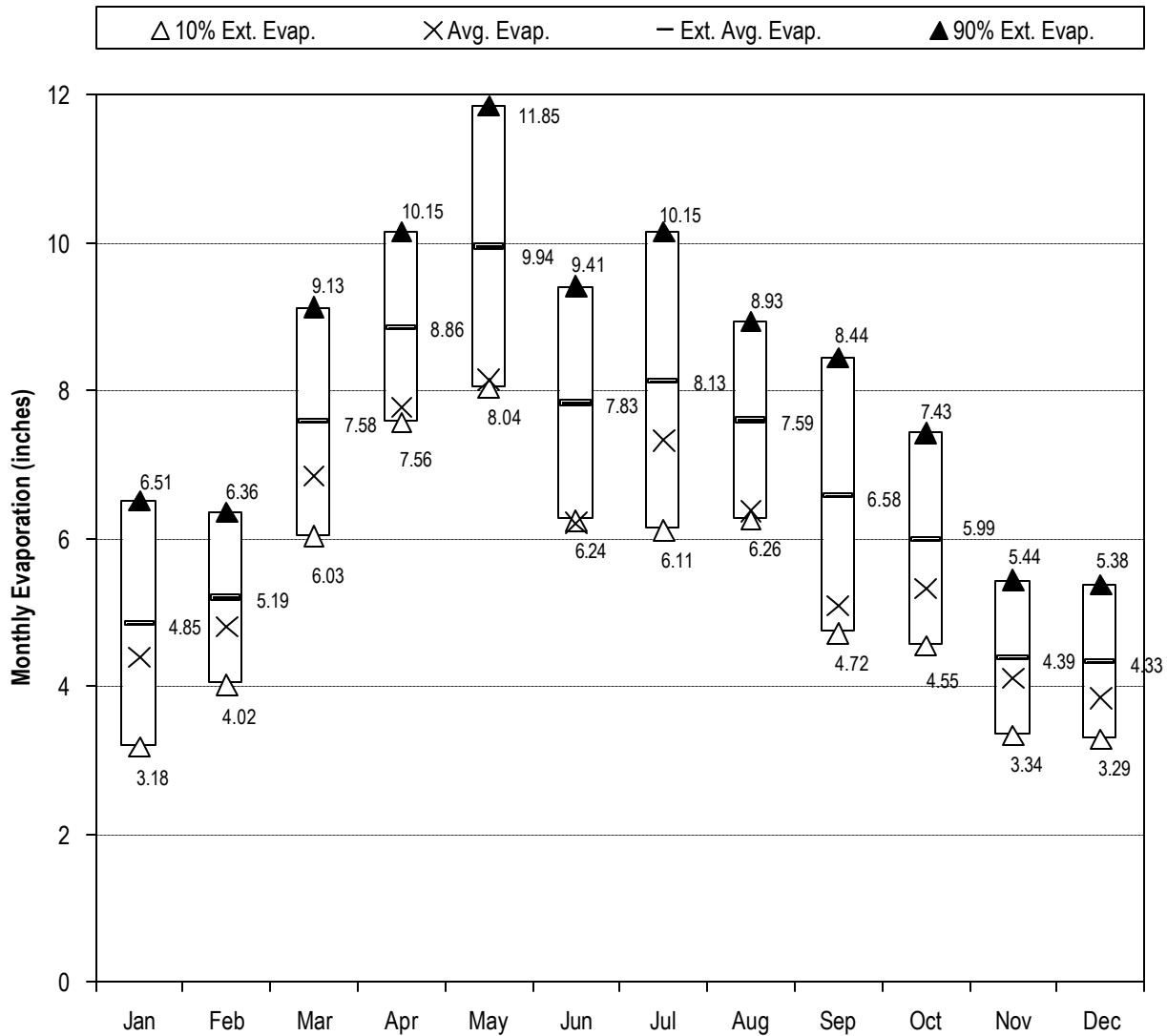
The data collected by the SFWMD has been focused on the Everglades. As observed previously, phosphorous and nitrogen data from the Everglades is expected to be very different from that in the Keys due to the affect of regional agriculture on the Everglades. Such activities are not present in the Keys.

At this time, no feasible data sets have been identified for incorporation into the CCAM. Aerial deposition data, which may be a substantial factor for many of the other modules that rely on weather related data, is sorely lacking due to an apparent lack of funding for related research within the Study Area.

3.1.7 Integration Considerations

The Weather Component, in its current form, provides look-up tables for selected weather related data. At the present time, this data is limited to rainfall and evaporation.

3.2 Potable Water Demand Component

Since there are no significant natural water supplies available in the Florida Keys to support and maintain human populations, the availability of potable water is an essential constraint to the carrying capacity of the Florida Keys. The Florida Keys Aqueduct Authority (FKAA) currently supplies potable water to residences and businesses, primarily by pumping fresh water in its pipeline, supplemented by a limited desalination capacity located within the Keys. Historically, significant development in the Keys has been directly related to the capacity and expansion of the central pipeline. Given the cost of producing water by desalination processes, it can reasonably be assumed that the availability of fresh water on the mainland, pumped through the pipeline to customers, will continue to be a controlling aspect of development, and a critical component in the carrying capacity of the Florida Keys.

The Potable Water Demand Component develops an estimate of daily potable water demand for each given scenario, and then compares the estimate against the allowable groundwater withdrawal of FKAA's current consumptive water use permit to determine whether the existing water system has adequate supply and treatment capacity to meet the required water demand. This component also generates a warning in the event that the scenario's potable water demand exceeds the permitted capacity of the FKAA's current facilities.

3.2.1 Ancillary Investigation Activities

A clear understanding of the potable water supply available to the Florida Keys is an essential component of the CCAM. A limited investigation of the FKAA's existing supply, permits and pipeline was undertaken as part of the Potable Water Demand Component. A summary of the information that was investigated and obtained to support the development of the Potable Water Demand Component is provided in Table 9.

TABLE 9
SUMMARY OF ANCILLARY INFORMATION
RELATED TO POTABLE WATER

Information/Document	Source
Parcel database in GIS format for the entire Florida Keys	CH2MHILL, Monroe County Sanitary Wastewater Master Plan (2000)
Monthly Water Use Records for Areas 2-5 (from FKAA)	CH2MHILL, Monroe County Sanitary Wastewater Master Plan (2000)
Monthly Water Use Records for Area 1, Key West	FKAA (2001)
Estimated water usage per equivalent dwelling unit for Key West	City of Key West Utilities Department
Water Treatment Plant Capacity Information	FKAA (2001)
Water Transmission Main Diameters	FKAA (2001)

All water supplied by FKAA to the Keys is treated potable water. At the present time FKAA does not provide a secondary quality supply of water in the Keys. All recovered water currently generated in the Keys is used in the proximity of the wastewater treatment facilities in which it is generated, on the same island in which it is generated, and that it is not distributed to other islands.

Monthly water usage for the 27 wastewater Study Areas presented in the *Monroe County Sanitary Wastewater Master Plan* (*Master Plan*) prepared by CH2MHILL in 2000, were based on water billing records provided by FKAA for their Billing Areas 2 through 5. Area 2 consists of Stock Island through Little Torch Key, which are Wastewater Study Areas 1 through 10. Area 3 includes Big Pine Key through Conch Key, which are Wastewater Study Areas 11 through 14. Wastewater Study Areas 15 through 19 comprise Area 4 from Long Key to Plantation. Area 5 includes Tavernier to Ocean Reef Club, which are Study Areas 20 through 27. Data for Key West (FKAA's Billing Area 1) was excluded in the Master Plan.

Monthly water use records for Key West were obtained from FKAA for the period of October 1997 through September 1998. Separate metering data for the City of Key West was not available prior to October 1997. The average monthly water usage for the Study Areas was calculated using the three years of available monthly water use records, with the exception of Key West (Area 1), which only had one-year of data. A summary of the average monthly water usage in the five FKAA billing areas is shown in Table 10. The monthly records for the three-year period are provided in Appendix A.

TABLE 10
FKAA MONTHLY AVERAGE WATER USE RECORDS
FOR THE FLORIDA KEYS

FKAA Billing Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Area 1	4.5	4.6	4.0	4.7	4.7	5.0	5.0	4.5	4.4	3.7	4.6	3.7
Area 2	1.7	1.7	1.6	1.8	1.7	1.8	1.7	1.7	1.6	1.3	1.5	1.5
Area 3	2.3	2.4	2.3	2.5	2.4	2.4	2.2	2.5	2.2	1.7	2.0	1.9
Area 4	1.5	1.5	1.5	1.7	1.5	1.7	1.6	1.6	1.5	1.0	1.3	1.2
Area 5	2.9	3.0	2.7	3.1	3.0	3.1	2.7	2.9	2.8	2.1	2.6	2.5
Total	12.8	13.3	12.1	13.9	13.3	14.0	13.3	13.1	12.5	9.8	12.1	10.8

Notes:
[1] All flows are in mgd.
[2] Areas 2 through 5 data based on 3 years of FKAA average monthly water use records (1995-1998).
[3] Area 1 data based on one year of FKAA average monthly use records (1997-1998).
[4] Monthly totals may not equal sum of Areas 1-5 due to rounding of significant figures.

Given the limited amounts of irrigated and maintained turf and formal landscaping in the Keys, it would appear that the benefit of secondary (non-potable) water supplies is very limited as a means of off-setting the use of potable waters for irrigation. Additionally, one of the central water conservation strategies being promoted by the Florida Department of Environmental Protection (FDEP) and SFWMD is the use of native vegetation, particularly xeriscaping, which is drought tolerant and adapted to seasonal rainfall patterns, in lieu of manicured turf and non-native landscaping that require irrigation.

3.2.2   Resulting Data

The results of the foregoing investigation and data acquisition/review activities have produced datasets for the Potable Water Demand Component that will be incorporated into the CCAM's database. New datasets that were developed address four areas of interest, which include the existing EDUs in the Keys, allocation of the estimated EDUs to existing parcels, potable water supply capacity, and transmission pipeline throughput capacity. Each of these elements is discussed in more detail in the following paragraphs.

Existing EDUs in the Study Area

FKAA supplies all of the potable water used in the Keys, with the exception of a few cisterns that are known to still be in use. A dataset was provided by FKAA, which contains the following information:

- Customer account number,
- Customer billing address, and
- Monthly or average water usage by customer.

During development of the *Monroe County Sanitary Wastewater Master Plan*, an attempt was made to utilize the FKAA database to estimate wastewater generation by linking the FKAA database with the Monroe County parcel database from the Property Appraiser' Office. However, difficulties were encountered due to incomplete Real Estate (RE) Numbers and data matching problems due to discrepancies in text entry. Therefore, water usage was assigned in the *Master Plan* per wastewater study area rather than by parcel.

The water use for each wastewater study area was utilized as a means of estimating existing EDUs by Study Area. Water use was calculated by multiplying the average water usage rate for each wastewater study area [gallons per day per equivalent dwelling unit (gpd/EDU)] by the estimated EDUs per Study Area. Water usage rates vary from 112 to 200 gpd/EDU in the 27 Study Areas with an average of 145 gpd/EDU. The water usage rate for each wastewater study area was calculated based on water use records, as described in the *Master Plan*.

Since the *Master Plan* did not include evaluation of Key West, an average water usage rate per EDU was needed for Key West. The City of Key West indicated that the current average daily water usage rate for Key West is approximately 132 gpd/EDU. FKAA also provided population data and number of total and seasonal housing units. However, this data could not be used to

verify the water usage rate in terms of "gallons per day per equivalent dwelling unit" since tourist and commercial usage could not be accounted for in the housing unit information. Table 11 summarizes the water usage rates in terms of gpd/EDU per Study Area and the total water use for each of the wastewater study areas.

Allocation of Existing EDUs at the Parcel Level

Development of a working Potable Water Demand Component under this investigation's scope includes estimation of water consumption at the parcel level. Estimating incremental and total future potable water demands for each scenario requires that the existing EDUs within each wastewater planning area be allocated in a consistent manner to the existing developed parcels within each wastewater planning area. This exercise was undertaken, but not completed, in *Monroe County's Sanitary Wastewater Master Plan*, which was only successful in allocation of approximately 46 percent of the EDUs.

A consistent EDU allocation dataset for the parcels in each wastewater planning area is essential to the estimation of potable water demands and subsequent assessment of generated wastewater volumes. This effort is a tedious task given the system of land use classifications in use in Monroe County and the inconsistencies in the *Monroe County Sanitary Wastewater Master Plan's* datasets and assumptions.

Allocation of existing EDUs at the parcel level was used in both the Potable Water Demand and Wastewater Components. Residential densities were based on planning level data for categories such as single- and multiple-family residential developments, and mixed-use commercial properties. Conservative values (on the upper end of the density ranges) were used in an attempt to match the water usage and wastewater flows for each wastewater study area in the *Monroe County Sanitary Wastewater Master Plan*.

Allocations were developed using best professional judgment for uses such as restaurants and hotels where typical water usage/wastewater generation data, such as the number of seats or number of hotel rooms, was not available. The assumed densities per land use categories that were used to estimate EDUs in the database are indicated in Table 12.

TABLE 11
ESTIMATED WATER USAGE RATES, TOTAL WATER DEMANDS AND EDUs
BY WASTEWATER STUDY AREA

No.	Wastewater Study Area	gpd/ EDU[1]	Total Water Demand[2] (mgd)	EDUs[3]
1	Stock Island	168	0.49	3,009
2	Boca Chica	149	0.38	2,555
3	Bay Point	119	0.04	362
4	Lower Sugarloaf	181	0.14	754
5	Upper Sugarloaf	156	0.09	573
6	Cudjoe Key	110	0.19	1,770
7	Summerland Key	149	0.42	2,810
8	Big Torch/Middle Torch Key	200	0.02	102
9	Ramrod Key	146	0.07	526
10	Little Torch Key	135	0.11	853
11	Big Pine Key	132	0.53	4,040
12	Bahia Honda/Ohio Key	160	0.08	490
13	Marathon Primary	160	1.41	8,796
14	Marathon Secondary	172	0.36	2,167
15	Long Key/Layton	116	0.11	978
16	Lower Matecumbe	151	0.18	1,250
17	Upper Matecumbe	167	0.42	2,491
18	Windley Key	150	0.14	926
19	Plantation Key	158	0.65	4,118
20	Tavernier, PAED 15	125	0.26	2,115
21	Rock Harbor, PAED 16	115	0.29	2,528
22	PAED 17	155	0.51	3,302
23	PAED 18	134	0.41	3,080
24	PAED 19 & 20	143	0.46	3,373
25	PAED 22	160	0.00	0
26	PAED 21	160	0.03	205
27	Ocean Reef Club	112	0.29	2,602
	SUBTOTAL[5]	**147[4]**	**8.09**	**55,775**
28	Key West	132	4.26	32,350
	TOTAL[5]	**147[4]**	**12.35**	**88,125**

Notes:
[1]   Based on information provided in Monroe County Sanitary Wastewater Master Plan (CH2MHILL, 2000) with the exception of Key West data, which was added by URS.
[2]   Calculated based on EDUs by URS and gpd/EDU.
[3]   EDUs estimated by URS.
[4]   Average value.
[5]   Totals may not equal sum of areas due to rounding of significant figures.

TABLE 12
ASSUMED DENSITY PER LAND USE CATEGORY

Land Use Category	PC Code[4]	Assumed Density (units/acre)
Single -Family - Residential	01	4
Multi-Family - Mobile Homes	02	10
Multi-Family - Condominiums	04	15
Multi-Family - General	08	15
Timeshare	05	15
Campgrounds	36	10
Mixed Use - Residential/Commercial	12	10
County, State, Federal Properties	86, 87, 88	4
Public School	83	5
Private School, College (Live-In)	82, 84	20
Hospital, Nursing Home	73, 74	20
Stores, Shopping Center	11, 16	10
Office Building	17	10
Tourist Attraction, Theater	35, 32	10
Hotel, Motel (Greater than 1 Acre)[1]	39	25
Restaurant (Greater than 1 Acre)[2]	21,22	20
Night Club	33	Varies[3]
Church	71	5

Notes:

[1]   Hotels or motels less than 1 acre were assigned a value of 25 EDUs.

[2]   Restaurants were assumed to have 20 EDUs for 1 acre or less. If > 1.0 acre then 20 EDU/acre.

[3]   Nightclubs were assumed to have varying EDUs based on acreage: 20 EDUs for 0.05 to 0.25 acre, 30 EDUs for 0.26 to 0.50 acre, and 40 EDUs for > 0.50 acre.

[4]   PC Code is the property code for various land uses from the Property Appraiser database.

The product of the area for each parcel and the assumed development density for the corresponding land use category was calculated for each parcel to represent the assumed EDUs. The total flow per wastewater study area was then compared to the flows provided in the *Monroe County Sanitary Wastewater Master Plan*, which were based on FKAA water use records. EDUs assigned to each parcel were then adjusted accordingly to increase or decrease flows per study area to be as close as reasonably possible to the values presented in the *Master Plan*.

Primary Potable Water Supply Capacity

Information was obtained from FKAA regarding the design capacity and the permitted withdrawal for their existing water treatment plant, which provides all of the potable water to the Keys. FKAA's existing water treatment plant is located in south Dade County and has a design capacity of 22 mgd. However, the facility's current SFWMD permit limits the annual average daily water withdrawal/usage to 15.83 mgd, with a peak daily limit of 19.19 mgd.

FKAA is currently expanding its water treatment plant, which will occur in two phases. The first phase, currently under construction, will increase the plant to 25 mgd. The projected completion date is late 2002. The second phase, currently under design, will increase the capacity to 30 mgd. The scheduled completion date for the Phase 2 expansion is 2004.

FKAA is currently working with SFWMD for modification to their existing permit conditions. FKAA anticipates that the new permit will be based on a maximum monthly water demand rather than a peak daily water demand. The available water use records indicate that maximum monthly water usage can increase up to approximately 15 mgd, with peak daily flows up to 20 mgd.

Secondary Potable Water Supply

FKAA's secondary potable water supply consists of the two existing reverse osmosis (RO) plants located in Stock Island (rated at 2.0 mgd) and Marathon Key (rated at 1.0 mgd). These plants were initially constructed as an emergency supply measure, are fully operational, but are not used for daily water production purposes.

The plants are operated on a regular intermittent basis to make sure that they are functional, but FKAA indicated that they do not keep water production records. Even if records were available, they would not be representative of how much water has been provided by the secondary supply due to actual necessity. While it is feasible that the secondary potable water supply system could be operated at its rated capacity of 3.0 mgd on a sustained basis, it would be extremely expensive and would also require the construction of additional units to exceed its current rated capacity of 3.0 mgd.

Transmission Pipeline Throughput Capacity

FKAA also indicated that the water transmission system extends a total of 130 miles from south Dade County to Key West. The transmission main sequentially reduces in diameter at three locations as it progresses south to Key West. Mile Markers indicate the start and end points of a respective pipe diameter of the transmission main, as indicated in Table 13.

TABLE 13
TRANSMISSION PIPELINE SIZE AND THROUGHPUT CAPACITY

Transmission Main From	Transmission Main To	Pipe Diameter	Estimated Capacity (mgd)
MM 130 (WTP)	MM 90	36" [1]	32.0
MM 90	MM 48	30" [2]	22.5
MM 48	Key West City Limits	24" [3]	14.5
Key West City Limits	End	18" [4]	8.0

Notes:
[1] Corresponds with FKAA Area 5.
[2] Serves FKAA Area 4 and a portion of Area 3.
[3] Serves remaining Area 3 and Area 2.
[4] Corresponds with FKAA Area 1.
[5] MM refers to Mile Marker.
Source: FKAA

Estimated transmission main capacities were calculated based on pipe diameter and a maximum design velocity of 7.0 feet per second, which is a typical upper limit in the industry. FKAA has indicated that the current plant expansion will include increased pumping capacity up to 30 mgd. This increased pumping capacity will result in a velocity of approximately 6.6 feet per second in the existing 36-inch water main.

FKAA is considering installation of a parallel water main extending approximately 18 miles south of the water plant. However, the proposed pump station upgrades are expected to accommodate the 30-mgd expansion, according to FKAA. Therefore, it was assumed that any necessary booster pumping stations along the route and any other transmission system upgrades have already been planned by FKAA to accommodate up to 30-mgd. Consequently, the existing pipelines were assumed to have upper-end velocities similar to the 36-inch main (7.0 feet per second) for the water transmission main capacity assessment of the Potable Water Demand Component.

The resulting water use demands will be compared to the established capacity limits of the transmission mains within the wastewater study areas. The total demand of the Florida Keys will also be compared to the summation of the water demands for the individual wastewater study areas.

3.2.3   Component Formulation

The Integrated Water Component, as described in the DO 5 Report, did not have a potable water demand component. The formulation of the Potable Water Demand Component contains two distinct elements that address water demand and permitted supply capacity, and these elements are discussed in more detail in the following paragraphs.

Estimation of Potable Water Demand

For each scenario, the daily potable water demand will be estimated based upon parcel-based land use and current water consumption rates. Data requirements include:

- Parcel-based land use,
- EDU allocation to currently developed parcels,
- EDU allocations by specific land-use types for new development, and
- Standardized demand rates per EDU by wastewater planning area.

Scenario input requirements include:

- Year in the simulation period, and
- Month of the year.

Computations will be aggregated to the level of the 28-wastewater planning areas (including Key West), and then summed to produce the estimated total potable water requirement for the entire Study Area for the given scenario.

Adequacy of the Permitted Supply

The module will also generate advisories and warning messages relative to water supply constraints associated with the FKAA's water supply and distribution system. Advisory messages will be generated based on the following considerations:

- Percent of primary supply that is being consumed by the scenario, and
- Percent of the permitted capacity that is being used by the scenario.

Specific warning messages that will be generated for a scenario include:

- Scenario Demand Exceeds Total Available Supply,
- Scenario Demand Exceeds Total Permitted Consumptive Use Limits, and
- Scenario Exceeds Conveyance Capacity of Pipeline Segment *X*.

In addition to existing water treatment plant capacity, the formulation of this component can be adjusted to accommodate incremental increases in water production/treatment capacity in the primary and secondary water treatment plants based upon future modifications to the graphical user interface (GUI).

This component also generates a warning in the event that the scenario's potable water demand exceeds the permitted capacity of the FKAA's current facilities. Data requirements include:

- Consumptive Water Use Permit limitations,
- Combined production capacity of primary water treatment plants,
- Combined production capacity of secondary water treatment plants, and
- Throughput limits for pipeline segments.

Scenario input requirements include:

- Whether secondary water treatment plants are to be included,
- Assumed production capacity increase in primary water treatment plant, and
- Assumed production capacity increase in secondary water treatment plants.

Computations will be aggregated to the level of the 28 wastewater planning areas, and then summed to produce the estimated total potable water requirement for the entire Study Area for the given scenario.

3.2.4   Enabling Assumptions

The enabling assumptions used in development of the Potable Water Demand Component include:

- The water usage rates (gpd/EDU) for the Study Areas are reasonably close to actual values.

- The primary means for water supply will be the 22 mgd water plant in south Dade County.

- The secondary means of water supply will be the reverse osmosis water plants that are used only under emergency conditions, and will not be considered in the determination of potable water supply normally available in the Study Area.

- The maximum velocity in the transmission main is 7 feet per second.

- The available water supply for 2002 will be 25 mgd (from the primary plant).

- The available water supply for 2004 will be 30 mgd (from the primary plant).

- Booster pumping stations and other necessary transmission system improvements have already been planned to accommodate the 30-mgd upgrade.

- Secondary water supplies, composed of reclaimed treated wastewater effluents, are so limited in terms of their available volume and potential distribution at the present time that they will not be considered in the CCAM.

3.2.5   Current Computational Algorithms

The Potable Water Component's algorithm will accommodate changes in the production of the daily supply of potable water. The default values are the existing permitted potable water capacity. Computational algorithms are used to multiply the estimated EDUs by the gpd/EDU for the respective wastewater study area to calculate the water demand per parcel, per wastewater study area and produce a grand total for the Study Area.

Algorithms that were developed for the Potable Water Demand Component are listed as follows:

Total Potable Water Demand in Individual Wastewater Study Area Calculation

$$TPWDx = EDUe(PWDe) + EDUn\ (PWDn)$$

Where:
TPWDx = Total Potable Water Demand for Study Area, x
x = Study Area 1 through 28
EDUe = Existing Equivalent Dwelling Unit
PWDe = Existing Potable Water Demand
EDUn = New Equivalent Dwelling Unit
PWDn = New Potable Water Demand

Total Potable Water Demand in Florida Keys Calculation

$$TPWD_{FK} = \sum_{1}^{28} TPWDx$$

Where:

TPWD$_{FK}$ = Total Potable Water Demand for FL Keys, FK
TPWDx = Total Potable Water Demand for Study Area, x
x = Study Area 1 through 28

Advisory Messages

1) % of Primary Supply $= \dfrac{TPWD_{FK}}{PRISUPP_{FK}} * 100$ % of Primary Supply Consumed

2) % of Secondary Supply $= \dfrac{TPWD_{FK}}{SECSUPP_{FK}} * 100$ % of Secondary Supply Consumed

3) % of Permitted Capacity $= \dfrac{TPWD_{FK}}{PERMCAP} * 100$ % of Permitted Capacity Used

Where:

TPWD$_{FK}$ = Total Potable Water Demand for Florida Keys, FK
PRISUPP$_{FK}$ = Primary Supply of Water in Florida Keys, FK
PERMCAP   = Permit Capacity
SECSUPP$_{FK}$ = Secondary Supply Water in Florida Keys, FK

Warning Messages

1.   If TPWD$_{FK}$ > PRISUPP$_{FK}$, then issue   Demand Exceeds Primary Supply

    Where:

TPWD$_{FK}$ = Total Potable Water Demand for Florida Keys, FK
PRISUPP$_{FK}$ = Primary Supply of Water in Florida Keys, FK

2.   If TPWD$_{FK}$ > PRISUPP$_{FK}$ + SECSUPP$_{FK}$, then issue   Demand Exceeds Primary and Secondary Supply

    Where:

TPWD$_{FK}$ = Total Potable Water Demand for Study Area, x
PRISUPP$_{FK}$ = Primary Supply Water in Florida Keys, FK
SECSUPP$_{FK}$ = Secondary Supply Water in Florida Keys, FK

3.   If TPWD$_{FK}$ > PERMCAP, then issue   Demand Exceeds Permit Capacity

    Where:

TPWD$_{FK}$ = Total Potable Water Demand for Study Area, x
PERMCAP   = Permit Capacity

4. If TPWDx > PIPECAPx, then issue $\boxed{\text{Demand Exceeds Pipeline Capacity}}$

Where:

TPWDx	= Total Potable Water Demand for Study Area, x
x	= Study Area 1 through 28
PIPECAPX	= Pipeline Capacity in Segment, X

3.2.6 Definition of Datasets

Dataset requirements for the Potable Water Demand Component include the following temporarily and spatially variable data:

- GIS coverage for scenario-based parcels, and

- GIS coverage for wastewater study areas.

Other datasets used in the Component development include:

- Water use rate in terms of gpd/EDU for each wastewater study area,

- EDUs per parcel in a wastewater dataset,

- Capacity of primary water plant per scenario year,

- Combined capacity of primary and secondary water plants per scenario year, and

- Water transmission main throughput capacities per pipe segments.

The necessary GIS coverages were developed for use in the respective Component. The water use rate dataset for the various wastewater study areas were developed in Excel as a lookup table, which will be converted to Arc/Info files for use in the Component program. Other datasets described above were also developed as lookup tables for use in the program. These datasets created for the Potable Water Demand Component are included in Appendix A.

3.2.7 Integration Considerations

There are no known integration considerations that would require manipulation to overcome obstacles in the Potable Water Demand Component.

3.3 Stormwater Component

The Stormwater Component utilizes land use from contributing drainage areas and associated pollutant loading rates to estimate pollutant loads discharged to the receiving surface water and groundwater systems. BMPs reduce the pollutant loads that are discharged. BMPs are included in the Stormwater Component using a list of potential practices and their associated removal rates for various pollutants.

The Stormwater Component performs the following basic functions:

- Computes runoff volumes for each delineated drainage area (catchment) based on input rainfall values and area-weighted runoff coefficients from a data table of land-use specific runoff characteristics.

- Computes loads for selected pollutants for each catchment using the computed runoff volumes and area-weighted event mean concentration (EMC) values from a data table of land-use specific EMC values for the selected pollutants.

- Computes pollutant load reductions for each catchment based on drainage areas served using data of potential BMPs and the associated removal efficiencies for the selected pollutants.

- Proportions and routes the computed runoff volumes and adjusted pollutant loads to the Groundwater Component (infiltration) and Immediate Nearshore Waters/Circulation Components (runoff).

In developing the Integrated Water Module, the Technical Contractor considered the comments and input gathered in the technical workshops. For example, comments and information provided by Bill Burnett at the workshop regarding the time of travel for effluents through the surficial groundwater were directly incorporated in the Groundwater Component.

3.3.1 Ancillary Investigation Activities

At the time of the development of this component, Monroe County was in the process of preparing a stormwater management master plan. Interim draft products of the study were used in the assessment of existing data and identification of potential data gaps. Additional data collection activities were focused on the development of representative runoff and EMC data for use in the Stormwater Component. Several data sources were consulted including Monroe County, the City of Key Colony Beach, SFWMD, and the EPA designated Municipal Separate Storm Sewer System (MS4) permitted communities in Florida. Internet and library searches were also conducted to help identify any other data sources that could be used.

Monroe County

As stated previously, at the time this was written, Monroe County was preparing the *Monroe County Stormwater Management Master Plan* through a contract with CDM. Volume 1 of the study was finalized in February 2001. That volume of the Master Plan included information regarding annual rainfall, EMC data, land use, estimated and projected pollutant loads, and BMP performance.

The *Monroe County Stormwater Master Plan* used the rational method to develop runoff volumes and this approach was subsequently adopted in the Islamorada stormwater master plan. The runoff coefficients used in the CCAM were calculated based on the impervious area values used in the *Monroe County/Islamorada Master Plans*. No runoff coefficient data specific to the Keys were identified in any studies.

City of Key Colony Beach

The City of Key Colony Beach received a Section 319 Nonpoint Source Management Program grant from EPA through FDEP to retrofit the city's stormwater system. A report titled *City of Key Colony Beach Stormwater Retrofit Project* was obtained. This report describes an array of BMPs constructed under Phase I and II of the City's retrofit project. The runoff modeling performed in the *Key Colony Beach Master Plan* used a high level of detail with a hydraulic routing model. Such detailed modeling is not appropriate for large-scale applications like the CCAM. The BMPs from the city's stormwater master plan were evaluated for inclusion in the CCAM.

The *Key Colony Beach Stormwater Master Plan* used pollutant loading rate data developed from several sources, including National Urban Runoff Program data. These same sources were used in the development of the DO 8 proposed loading rates, augmented with the more recent MS4 data from the Florida communities. No pollutant loading data specific to the Keys were identified.

City of Islamorada

The *Stormwater Master Plan for Islamorada* (2000) was obtained and reviewed for data that could be used for the development of data sets in DO 8.

The pollutant loading rates and modeling approach in the *Islamorada Stormwater Master Plan* were taken from the *Preliminary Monroe County Stormwater Master Plan*. The data from the Monroe County plan is discussed elsewhere in this report.

The BMPs from the village's stormwater master plan were evaluated for inclusion in the CCAM.

City of Key West

The City of Key West was contacted regarding stormwater master plans or studies, but none were identified.

South Florida Water Management District

A review of the SFWMD listing of technical publications did not reveal any published stormwater investigations of the Florida Keys. A report was found on stormwater runoff and pollutant loadings in South Florida titled *TP 88-9 An Assessment of Urban Land Use/Stormwater Runoff Quality Relationships and Treatment Efficiencies of Selected Stormwater Management Systems,* by P. Whalen and M. Cullum. The report assessed reported stormwater runoff quality for different land uses throughout Florida and compared the data to studies across the country. The data in this report was included in a publication by Environmental Research and Design (ERD), *Stormwater Loading Rates for Central and South Florida*, which was used by CDM in the development of the *Monroe County Stormwater Management Master Plan*.

Florida MS4 Communities

No monitoring data, studies or reports were identified that characterized runoff in the Florida Keys. To better address and characterize the nature of local runoff (i.e., Florida/South Florida), stormwater monitoring data was requested from each EPA-designated MS4 community in Florida. One of EPA's application requirements for these communities was the characterization of stormwater runoff and the computation of annual pollutant loads. This data has the benefit of being more recent than most of the data collected in other studies and while not actually from the Keys was at least developed from the general region. Table 14 lists the Florida MS4 communities and the status of the data collected.

All the collected Florida MS4 data was used to develop the proposed EMC values, including data from Tallahassee and the Orlando area. These data were adopted for use in the model and are considered the most representative of the potential stormwater runoff characteristics in the Keys. No attempt was made to screen out any of the Florida MS4 data. The *Monroe County Stormwater Master Plan* also used these data, as well as those from older sources and areas outside the state of Florida.

3.3.2 Resulting Data

Event Mean Concentration

Stormwater monitoring data from seventeen MS4 communities were collected. These data characterized stormwater runoff per land use for the common pollutants of concern. The stormwater monitoring data had a range of samples of 1 to 7 land uses, and 1 to 11 storm events per community. EMC values were computed for the average, 10-percentile and 90-percentile values for the development of uncertainty analysis using a lognormal distribution. These MS4 EMC values were then compared to the CDM and ERD EMC values.

Table 13 presents a comparison of the EMCs values from the various sources. Figures 12 through 24 show graphical comparisons of the data presented in Table 15. The EMC values developed in this report, based exclusively on recent Florida only data, are more likely to be representative of runoff in the Keys than the EMC values used in the Monroe County study due to CDM's inclusion of non-Florida stormwater runoff data. A sufficient number of EMC values were found to adequately estimate the average, 10 percent and 90 percent values.

TABLE 14
FLORIDA PHASE I MS4 COMMUNITIES

MS4 Community	Performed Monitoring?	Data Received?	Land Uses	Storm Events
Broward County	Yes	Yes	6	11
City of Bradenton	Yes	No		
City of Ft. Lauderdale	Yes	Yes	5	3
City of Hialeah	Yes	No		
City of Hollywood	Yes	Yes	1	1
City of Jacksonville	Yes	Yes	5	3
City of Jacksonville Beach	Yes	No		
City of Miami	Yes	No		
City of Neptune Beach	Yes	No		
City of Orlando	Yes	Yes	5	3
City of St Petersburg	Yes	Yes	5	3
City of Tallahassee	Yes	Yes	5	3
City of Tampa	Yes	Yes	5	3
City of Temple Terrace	Yes	Yes	2	3
Dade County	Yes	No		
Escambia County	No	No		
Hillsborough County	Yes	Yes	6	3
Lee County	Yes	No		
Leon County	Yes	Yes	3	3
Manatee County	Yes	No	5	3
Orange County	Yes	Yes	5	3
Palm Beach County	Yes	Yes	7	3
Pasco County	No	No		
Pinellas County	Yes	Yes	6	3
Polk County	Yes	Yes	5	6
Reedy Creek Improvement District	No	No		
Sarasota County	Yes	Yes	7	3
Seminole County	Yes	Yes	3	3

TABLE 15
EMC COMPARISONS

Land Use/ Parameter	MS4 EMC (mg/l)	Low MS4 EMC (mg/l)	High MS4 EMC (mg/l)	MS4 # of Obs.	CDM EMC (mg/l)	ERD EMC (mg/l)
Low Density Residential (LDR)						
TN	2.95	1.35	17.53	25	1.97	1.77
TKN	2.36	1.08	13.96	34	1.34	
$NO_2 + NO_3$	1.03	0.44	5.77	26	0.63	
TP	0.39	0.17	2.27	34	0.44	0.177
OP	0.21	0.10	1.25	34	0.33	0.077
BOD	9	4	54	35	15	4.4
COD	74	32	415	34	71	
TSS	35	16	206	35	27	19.1
TDS	134	61	794	35	286	
Cd	0.0029	0.0013	0.0171	28	0.0020	
Cu	0.0185	0.0084	0.1092	30	0.0090	
Pb	0.0166	0.0076	0.0981	23	0.0020	0.0370
Zn	0.0723	0.0331	0.4295	34	0.0510	0.0320
Medium Density Residential (MDR)						
TN	1.62	0.71	9.20	43		2.29
TKN	1.26	0.56	7.28	48	1.77	
$NO_2 + NO_3$	0.30	0.13	1.72	43	0.27	
TP	0.46	0.20	2.64	48	0.45	0.30
OP	0.25	0.11	1.43	47	0.27	0.15
BOD	12	5	71	41	9	7.4
COD	54	23	302	48	65	
TSS	32	14	188	47	59	27
TDS	92	40	525	47	59	
Cd	0.0013	0.0006	0.0073	23	0.0010	
Cu	0.0219	0.0100	0.1294	35	0.0070	
Pb	0.0157	0.0069	0.0898	41	0.0130	0.0480
Zn	0.0580	0.0260	0.3375	42	0.0570	0.0570
High Density Residential (HDR)						
TN	2.09	0.95	12.34	43		2.42
TKN	1.29	0.57	7.44	57	1.03	
$NO_2 + NO_3$	0.89	0.39	5.07	45	0.67	
TP	0.32	0.14	1.88	59	0.20	0.49
OP	0.19	0.09	1.11	56	0.09	0.27
BOD	15	6	79	55	8	11
COD	69	32	410	58	53	
TSS	23	10	135	56	42	71.7
TDS	287	103	1,336	57	141	
Cd	0.0019	0.0008	0.0106	38	0.0010	
Cu	0.0639	0.0229	0.2966	49	0.0220	
Pb	0.0111	0.0049	0.0633	40	0.0110	0.0870
Zn	0.0522	0.0230	0.2985	54	0.0650	0.0550

TABLE 15
(Continued)
EMC COMPARISONS

Land Use/ Parameter	MS4 EMC (mg/l)	Low MS4 EMC (mg/l)	High MS4 EMC (mg/l)	MS4 # of Obs.	CDM EMC (mg/l)	ERD EMC (mg/l)
Commercial/ Office/Public (COM)						
TN	2.04	0.93	12.02	61		2.01
TKN	1.55	0.70	9.13	76	1.03	
$NO_2 + NO_3$	0.66	0.29	3.80	63	0.67	
TP	0.32	0.15	1.92	77	0.20	0.29
OP	0.17	0.08	1.03	73	0.09	0.18
BOD	25	9	123	70	8	12.7
COD	87	39	508	77	53	
TSS	57	26	332	74	42	87.65
TDS	233	95	1,239	77	141	
Cd	0.0033	0.0015	0.0195	43	0.0010	
Cu	0.0193	0.0088	0.1141	59	0.0220	
Pb	0.0181	0.0080	0.1039	56	0.0110	0.1750
Zn	0.1100	0.0503	0.6531	74	0.0650	0.1405
Industrial (IND)						
TN	2.89	1.32	17.12	55		1.79
TKN	1.32	0.57	7.38	75	1.47	
$NO_2 + NO_3$	0.80	0.34	4.38	56	0.40	
TP	0.44	0.20	2.57	75	0.28	0.31
OP	0.22	0.10	1.30	71	0.20	0.13
BOD	11	5	61	73	14	9.6
COD	67	29	379	74	83	
TSS	68	30	396	72	77	93.9
TDS	172	79	1,020	71	130	
Cd	0.0071	0.0027	0.0355	36	0.0010	
Cu	0.0765	0.0253	0.3285	59	0.0240	
Pb	0.0621	0.0261	0.3392	61	0.0230	0.2020
Zn	0.1302	0.0590	0.7658	70	0.1320	0.1220
Roadway (RD)						
TN	1.44	0.57	7.45	9		2.08
TKN	1.46	0.61	7.96	18	1.51	
$NO_2 + NO_3$	0.26	0.12	1.51	9	0.34	
TP	0.26	0.12	1.57	18	0.40	0.34
OP	0.08	0.03	0.45	17	0.15	0.14
BOD	8	4	49	18	11	5.6
COD	77	33	425	18	99	
TSS	40	18	239	17	121	50.3
TDS	132	59	766	18	189	
Cd	0.0016	0.0007	0.0088	15	0.0020	
Cu	0.0170	0.0069	0.0895	16	0.0220	
Pb	0.0250	0.0069	0.0901	6	0.0390	0.1890
Zn	0.0482	0.0220	0.2856	17	0.1890	0.1340

TABLE 15
(Continued)
EMC COMPARISONS

Land Use/ Parameter	MS4 EMC (mg/l)	Low MS4 EMC (mg/l)	High MS4 EMC (mg/l)	MS4 # of Obs.	CDM EMC (mg/l)	ERD EMC (mg/l)
Open Space/Recreational (OPEN)						
TN	1.48	0.57	7.44	12		1.25
TKN	1.29	0.49	6.38	12	0.94	
$NO_2 + NO_3$	0.15	0.07	0.87	12	0.31	
TP	0.34	0.15	1.99	12	0.05	0.053
OP	0.22	0.10	1.26	12	0	0.004
BOD	11	5	67	12	1	1.45
COD	80	37	474	12	51	
TSS	31	14	182	12	11	11.1
TDS	118	50	651	12	100	
Cd	0.0033	0.0015	0.0189	10	0	
Cu	0.0115	0.0051	0.0657	10	0	
Pb	0.0110	0.0050	0.0643	10	0	0.0250
Zn	0.0150	0.0069	0.0890	10	0	0.0060
Agricultural (AGR)						
TN	3.36	1.19	15.45	3		2.32
TKN	2.23	0.79	10.19	3	1.74	
$NO_2 + NO_3$	0.96	0.37	4.75	3	0.58	
TP	1.09	0.50	6.50	3	0.34	0.344
OP	0.68	0.31	4.03	3	0.23	0.227
BOD	53	-	-	1	4	3.80
COD	50	23	293	3	51	
TSS	13	5	59	3	55	55.3
TDS	631	272	3,526	3	100	
Cd	0.0290	-	-	1	-	
Cu	0.0636	0.0253	0.3282	2	-	
Pb	-	-	-		-	
Zn	0.0420	-	-	1	-	
Wetlands (WL)						
TN				0	1.38	1.6
TKN				0	0.79	1.2
$NO_2 + NO_3$				0	0.59	0.4
TP				0	0.08	0.19
OP				0	0.044	0.13
BOD				0	4	4.63
COD				0	6	
TSS				0	6	10.2
TDS				0	12	
Cd				0	0.001	
Cu				0	0.007	
Pb				0	0.011	0.025
Zn				0	0.03	0.006

TABLE 15
(Continued)
EMC COMPARISONS

Land Use/ Parameter	MS4 EMC (mg/l)	Low MS4 EMC (mg/l)	High MS4 EMC (mg/l)	MS4 # of Obs.	CDM EMC (mg/l)	ERD EMC (mg/l)
Open Water/Lakes (OW)						
TN				0	1.38	1.25
TKN				0	0.79	0.9375
$NO_2 + NO_3$				0	0.59	0.3125
TP				0	0.08	0.11
OP				0	0.044	0.05
BOD				0	4	1.6
COD				0	6	
TSS				0	6	3.1
TDS				0	12	
Cd				0	0.001	
Cu				0	0.007	
Pb				0	0.011	0.025
Zn				0	0.03	0.028

FIGURE 12
EMC CHART COMPARISON
TOTAL NITROGEN (TN)
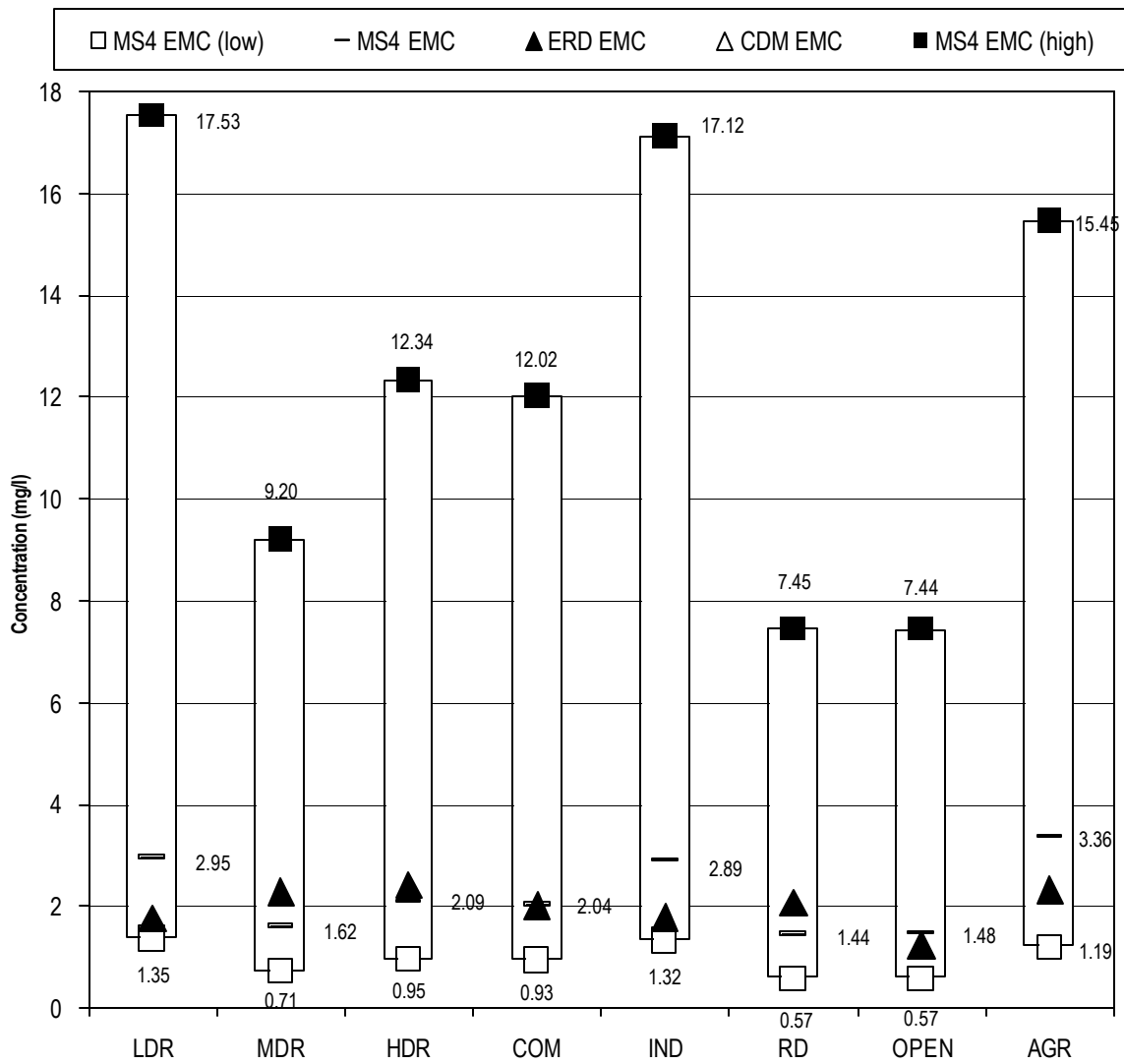
FIGURE 13
EMC CHART COMPARISON
TOTAL KJELDAHL NITROGEN (TKN)
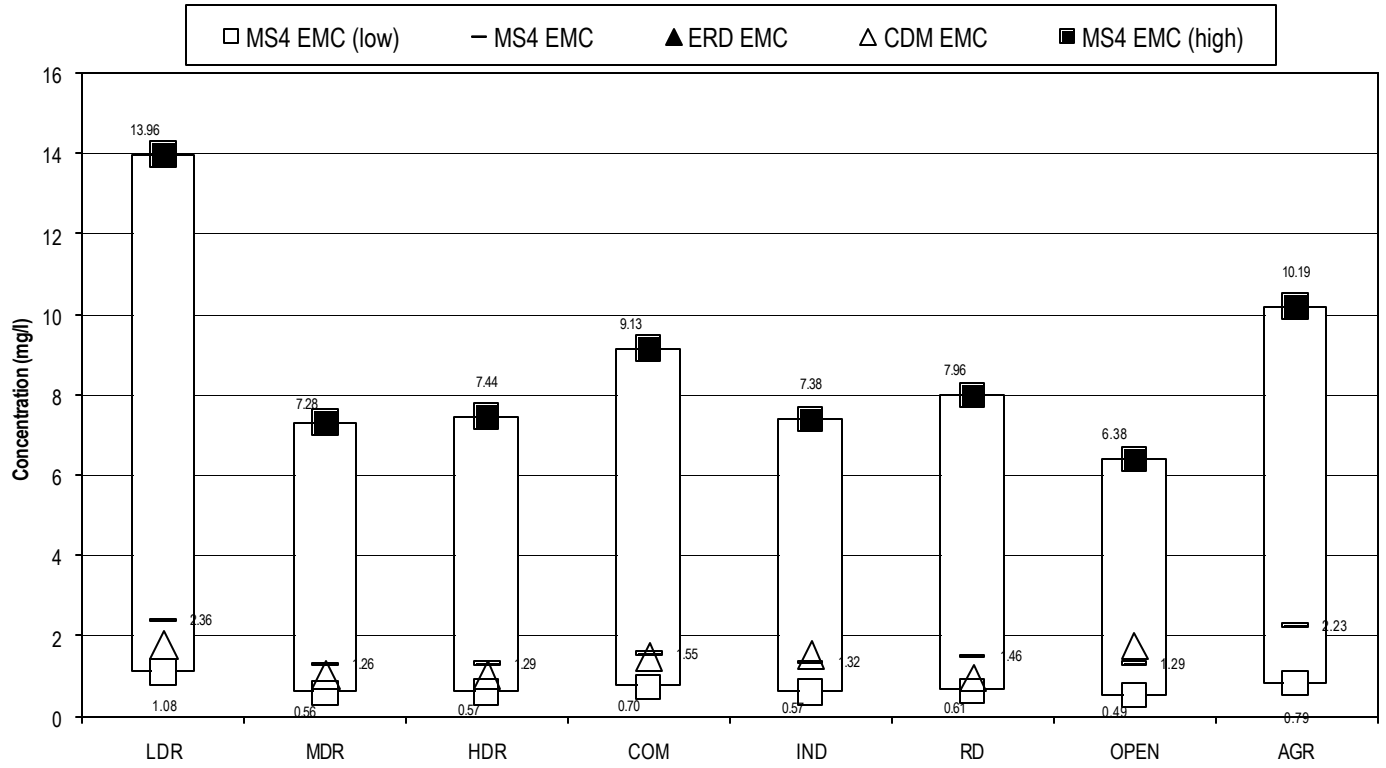
FIGURE 14
EMC CHART COMPARISON
NITRITE + NITRATE (NO$_2$ + NO$_3$ OR NO$_X$)
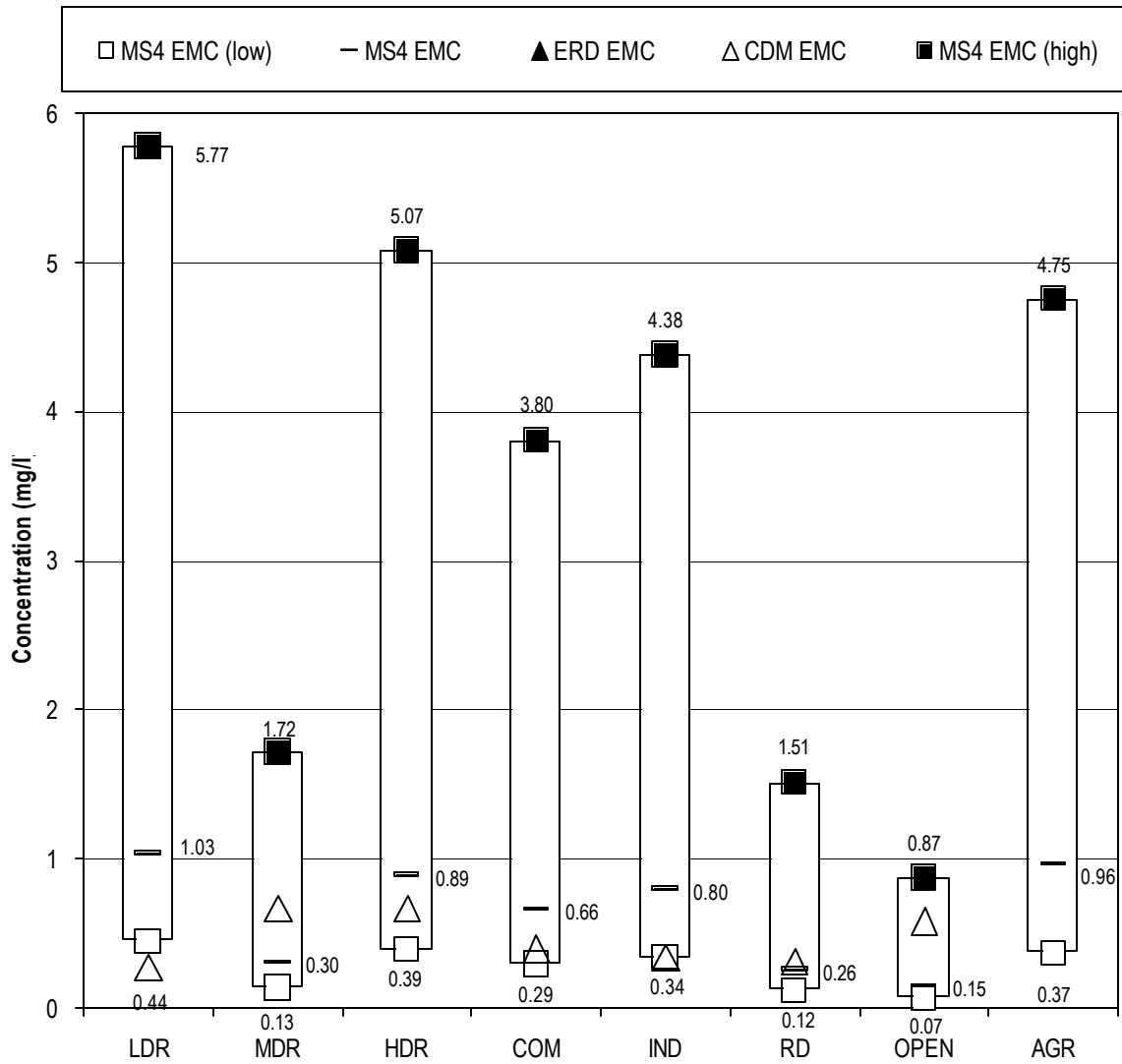
FIGURE 15
EMC CHART COMPARISON
TOTAL PHOSPHOROUS (TP)
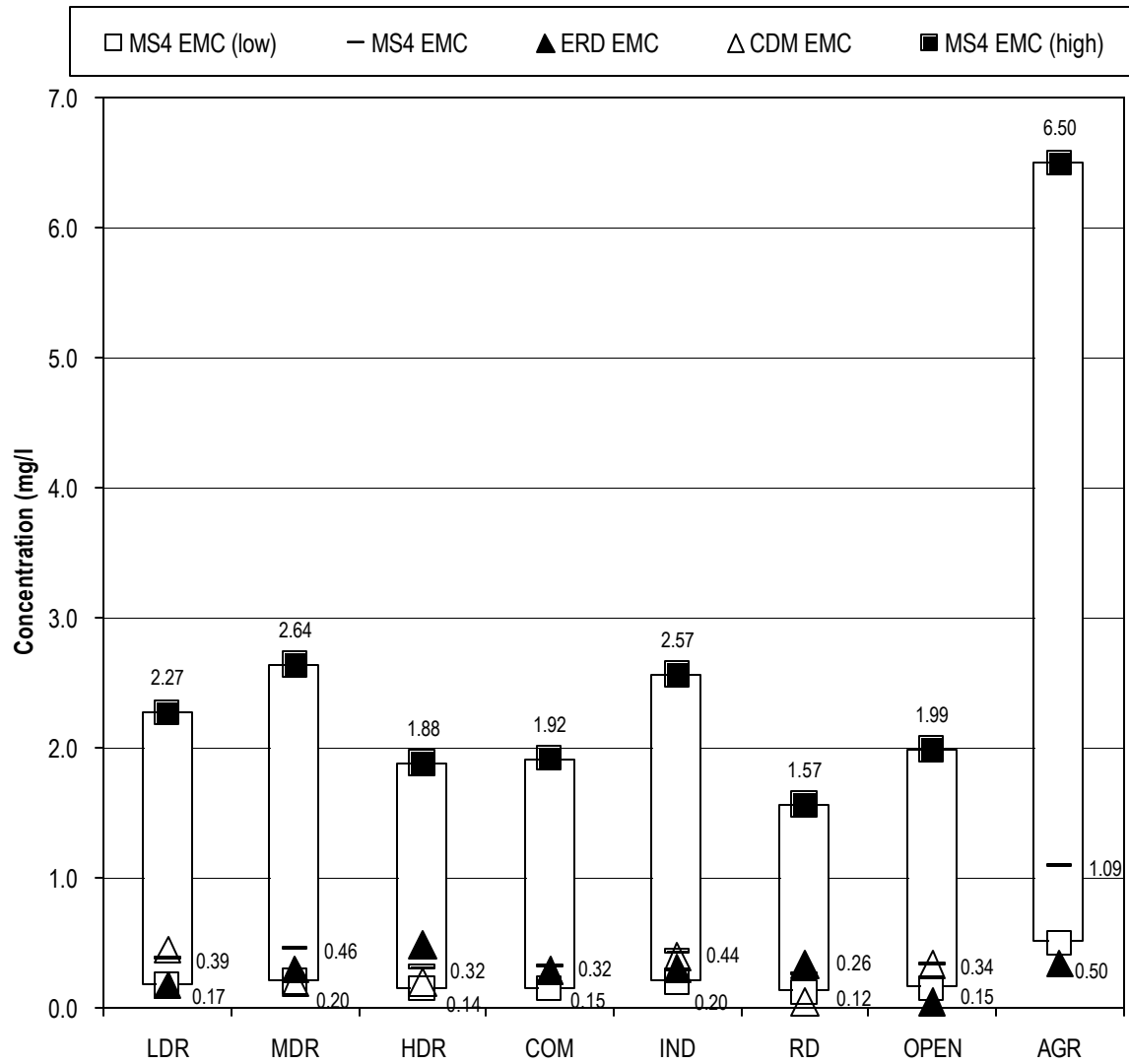
FIGURE 16
EMC CHART COMPARISON
ORTHO-PHOSPHOROUS (OP)
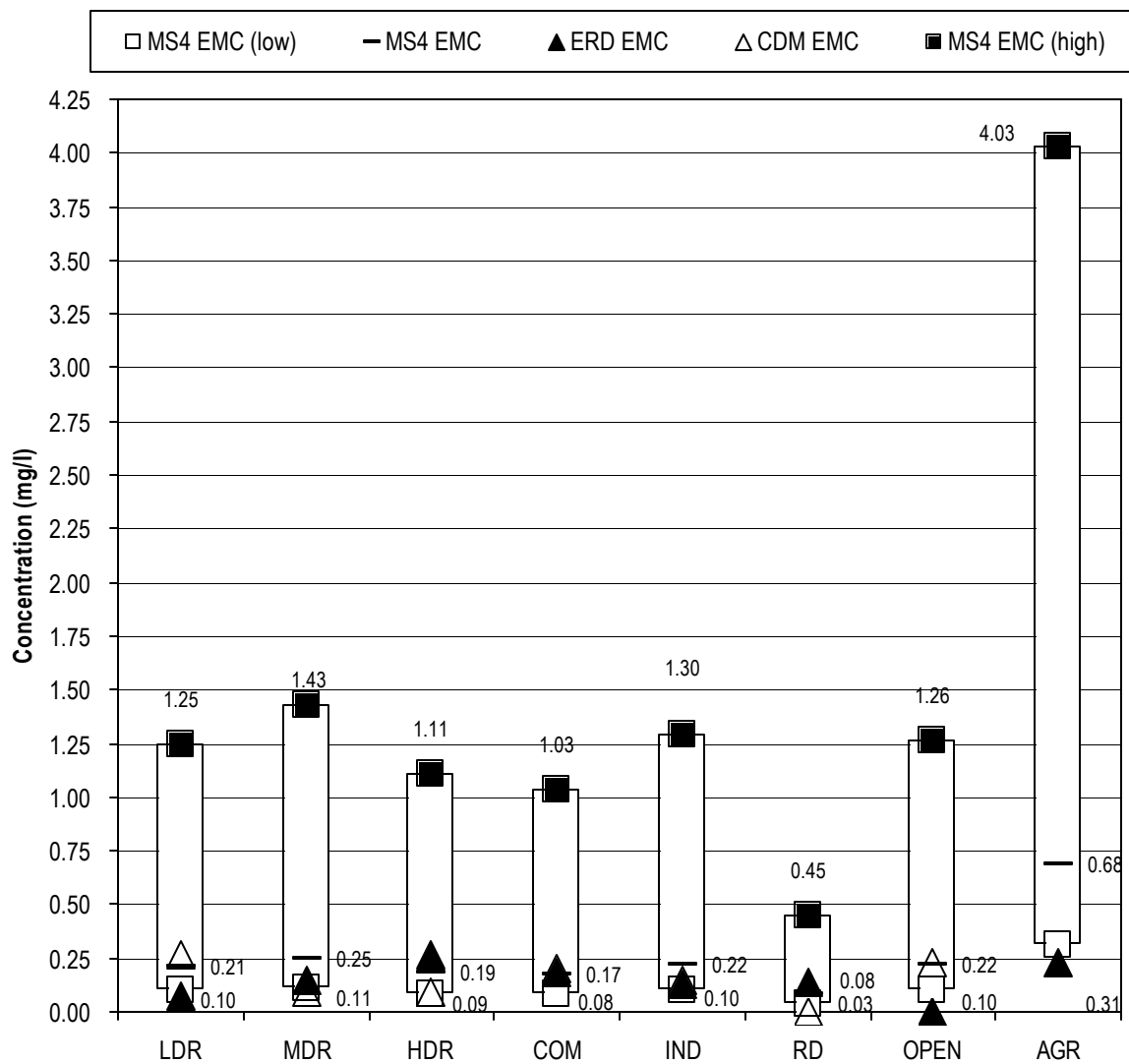
FIGURE 17
EMC CHART COMPARISON
BIOCHEMICAL OXYGEN DEMAND (BOD)
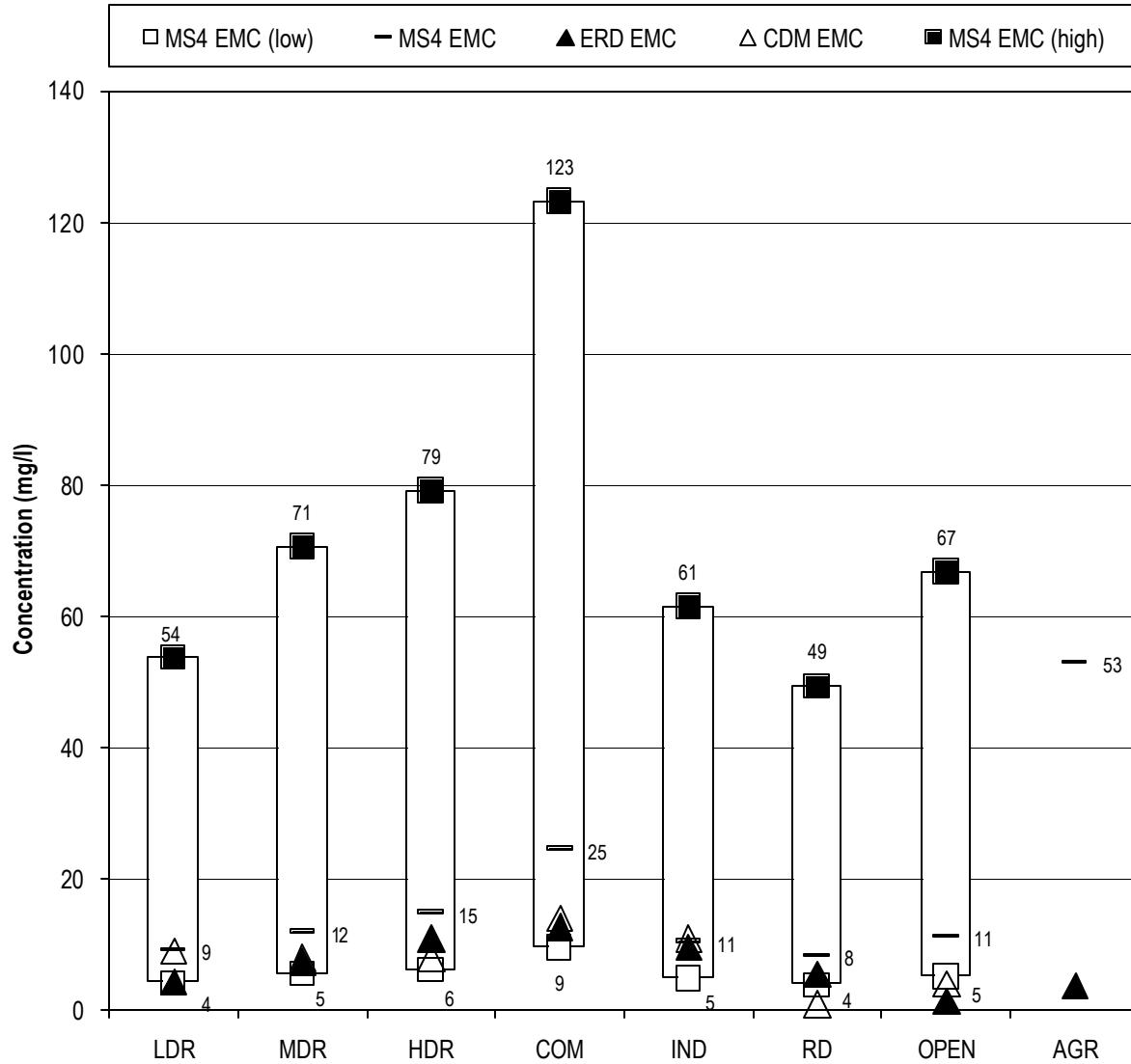
FIGURE 18
EMC CHART COMPARISON
CHEMICAL OXYGEN DEMAND (COD)

60
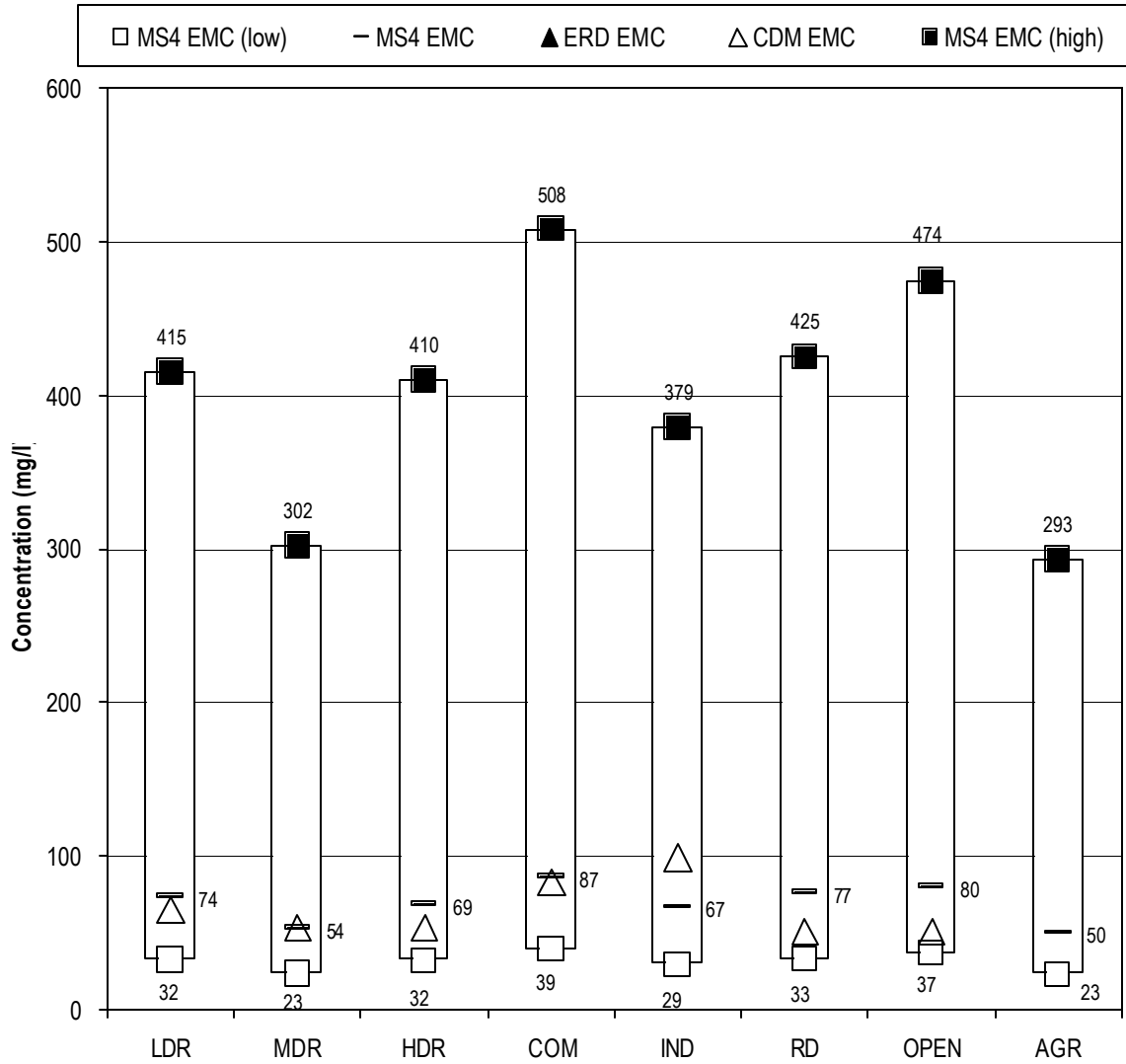
FIGURE 19
EMC CHART COMPARISON
TOTAL SUSPENDED SOLIDS (TSS)
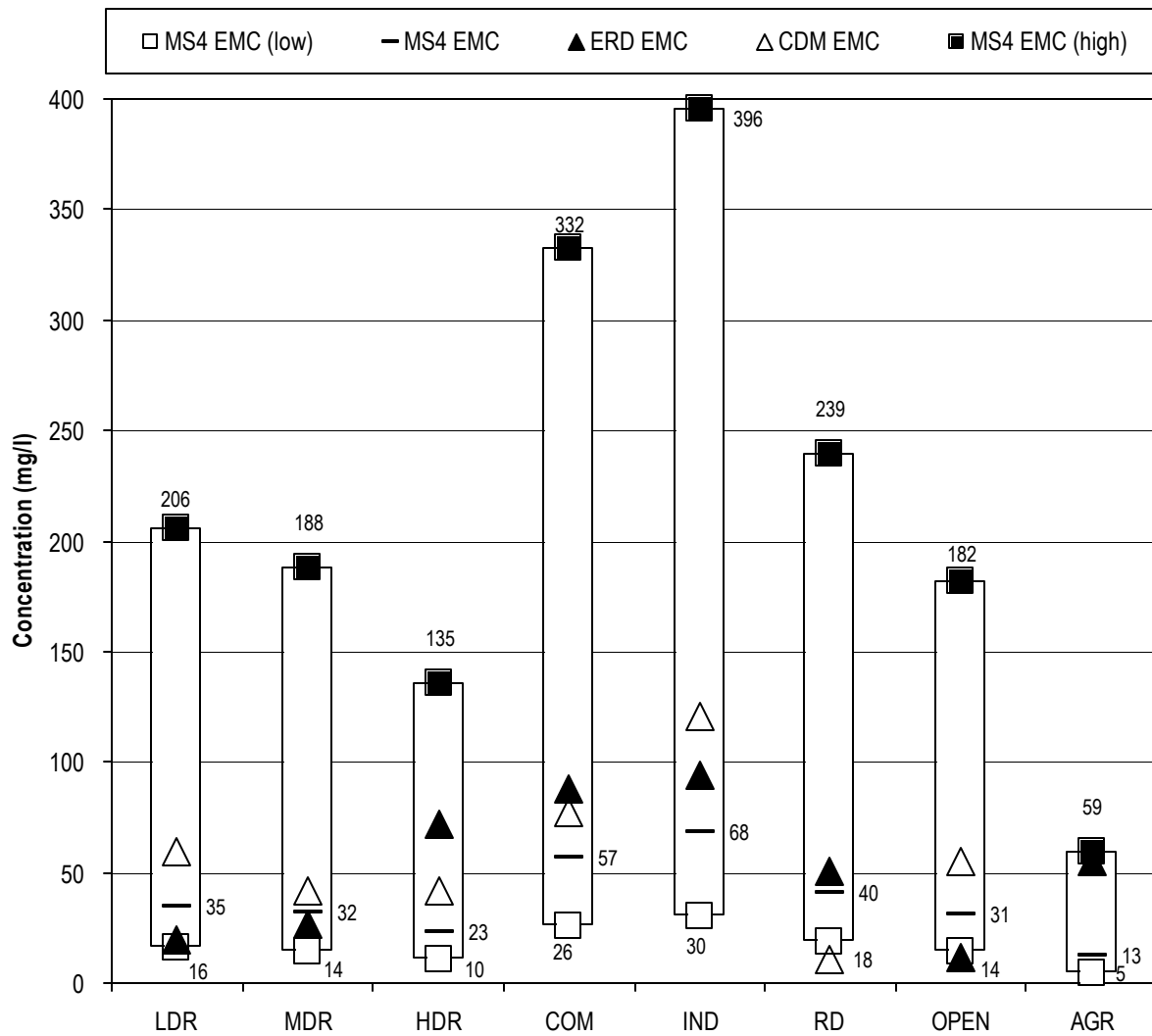
FIGURE 20
EMC CHART COMPARISON
TOTAL DISSOLVED SOLIDS (TDS)
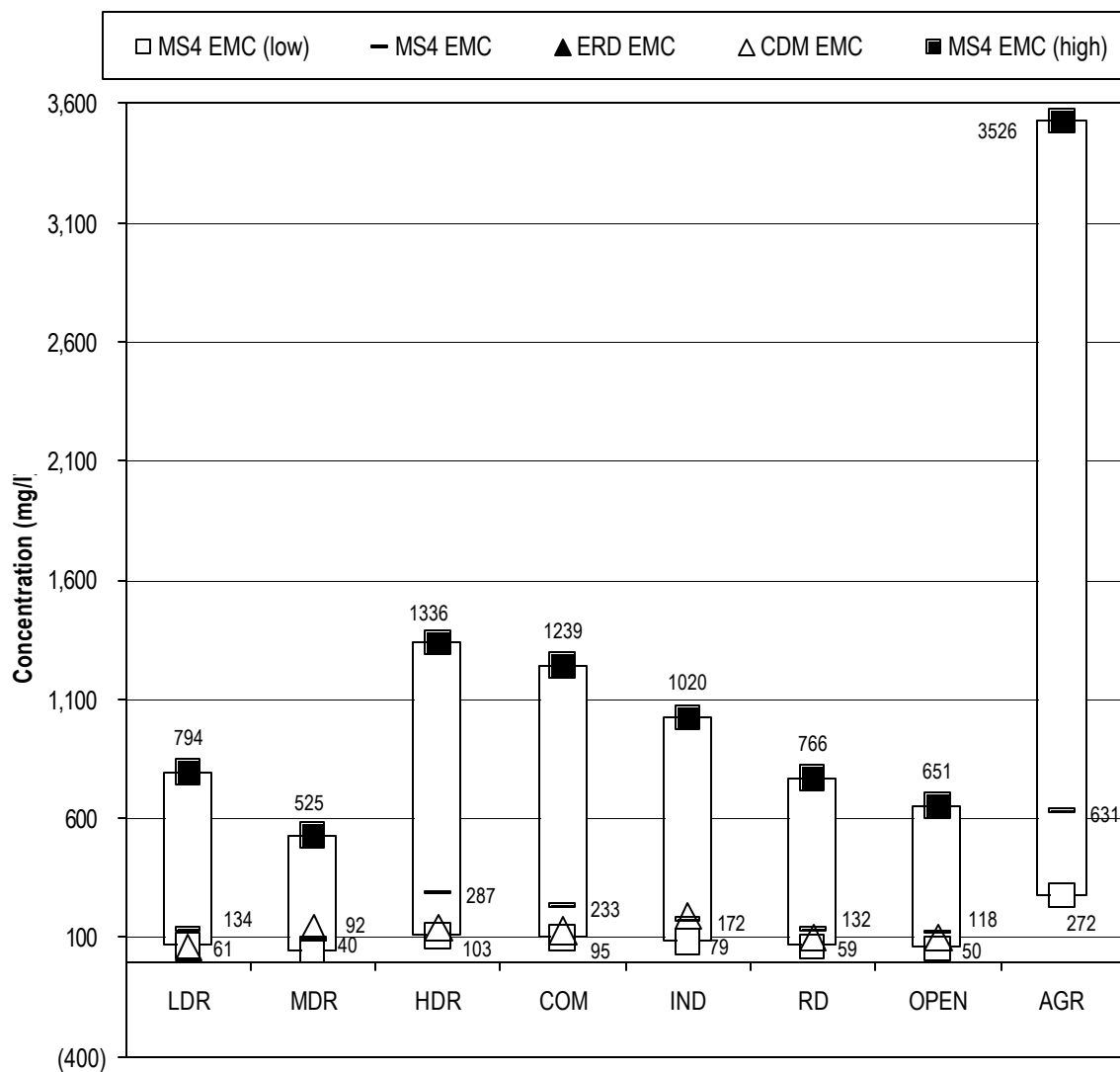
FIGURE 21
EMC CHART COMPARISON
TOTAL CADMIUM (CD)
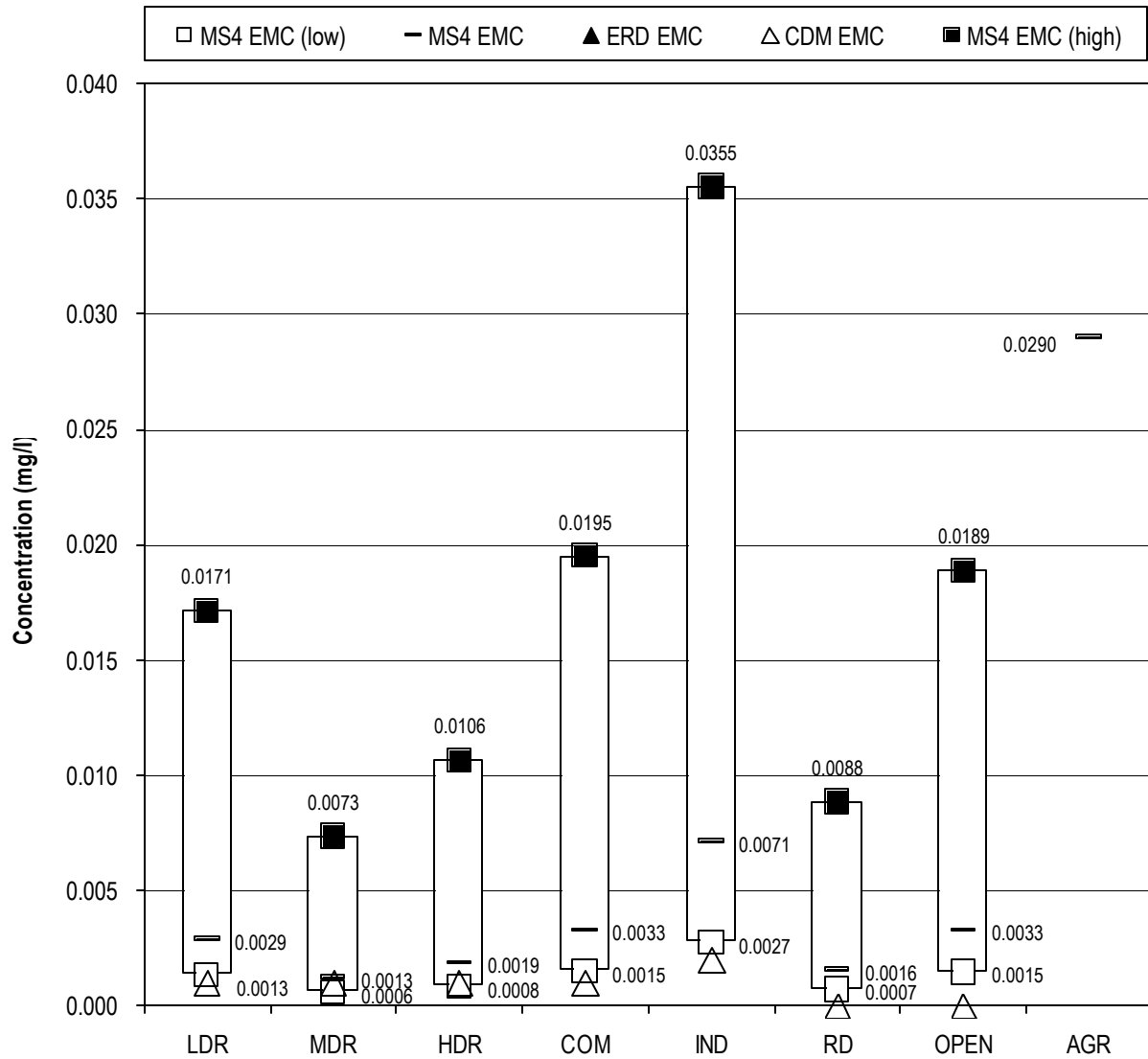
FIGURE 22
EMC CHART COMPARISON
TOTAL COPPER (CU)
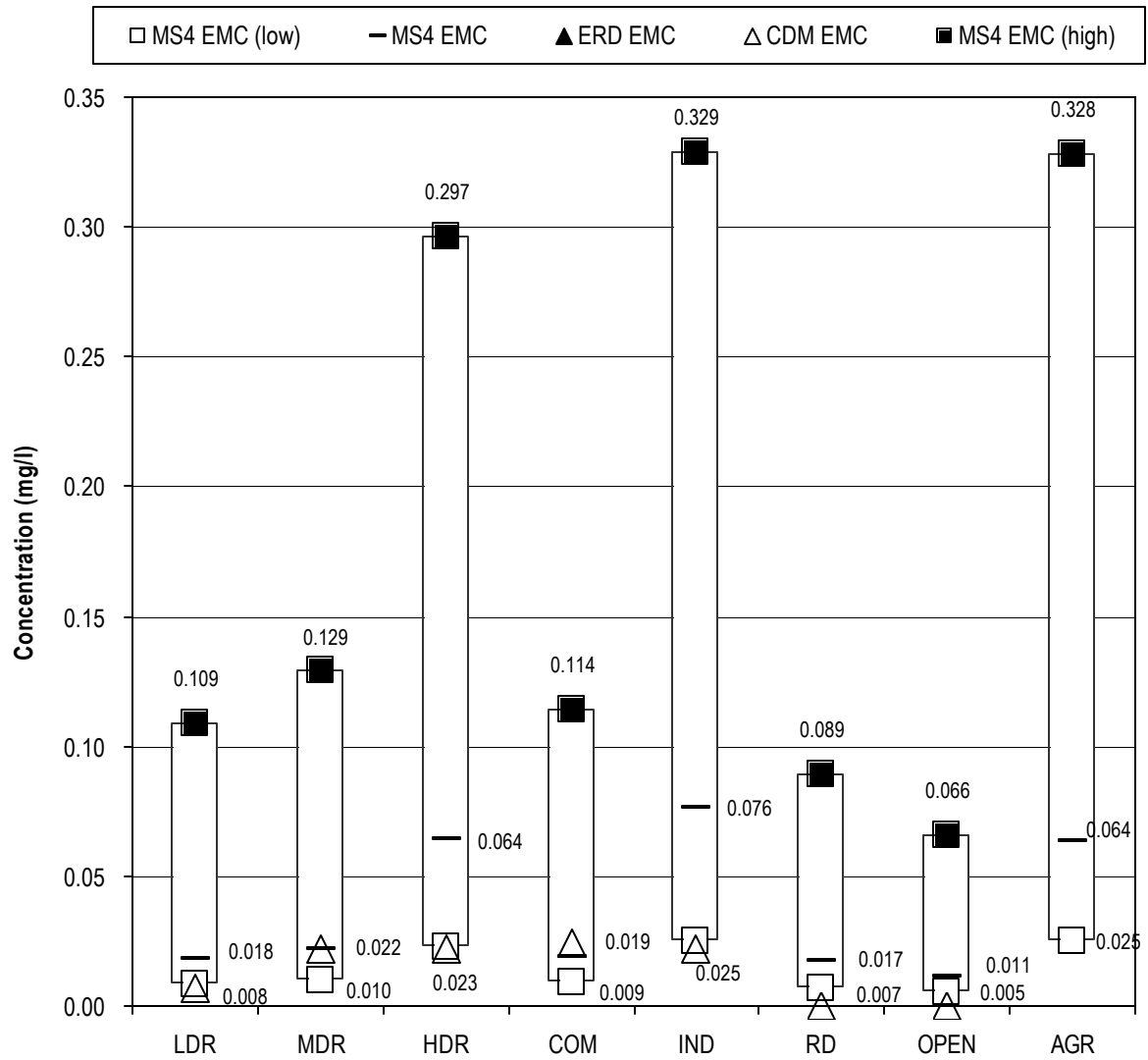
FIGURE 23
EMC CHART COMPARISON
TOTAL LEAD (PB)
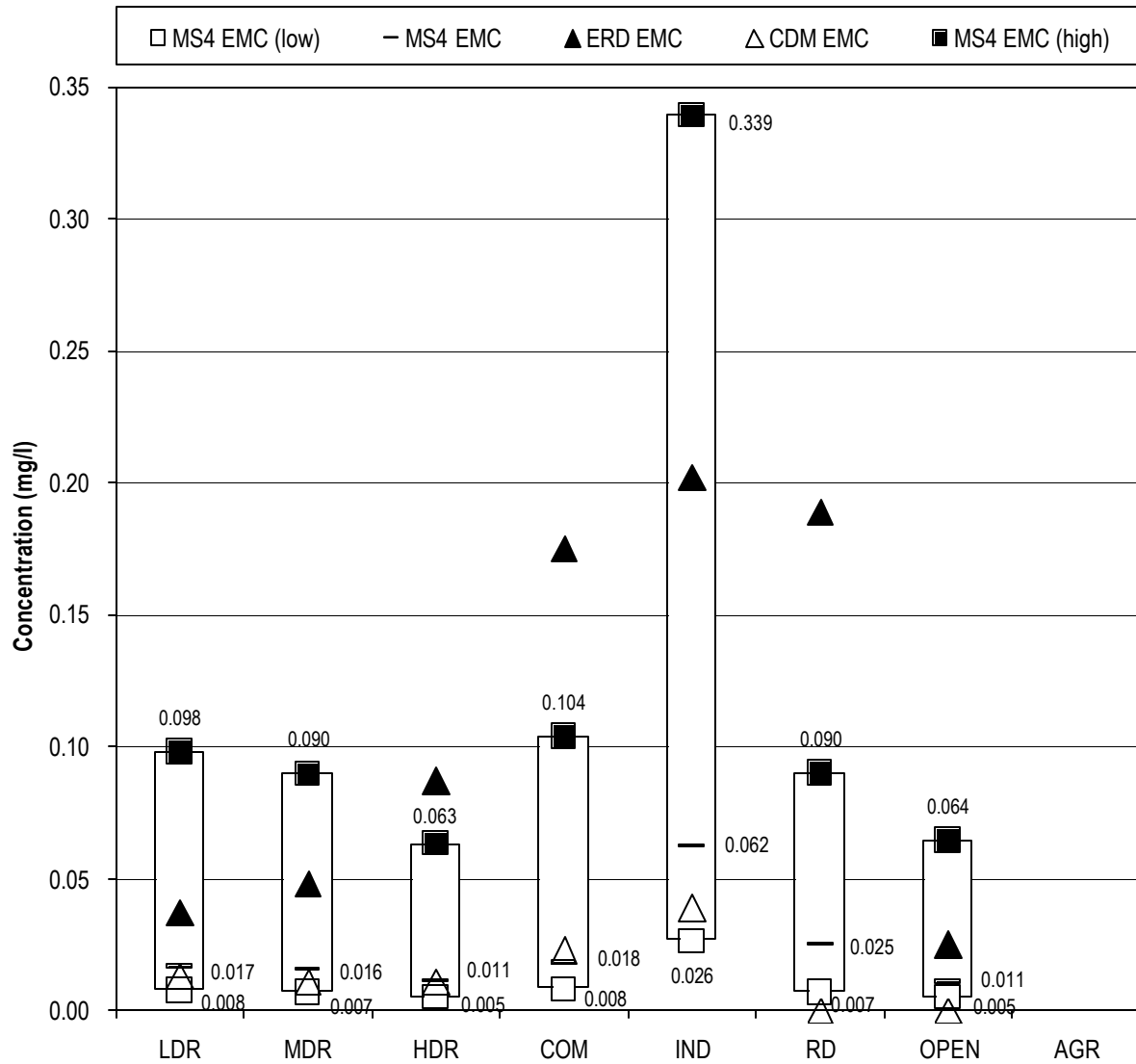
FIGURE 24
EMC CHART COMPARISON
TOTAL ZINC (ZN)
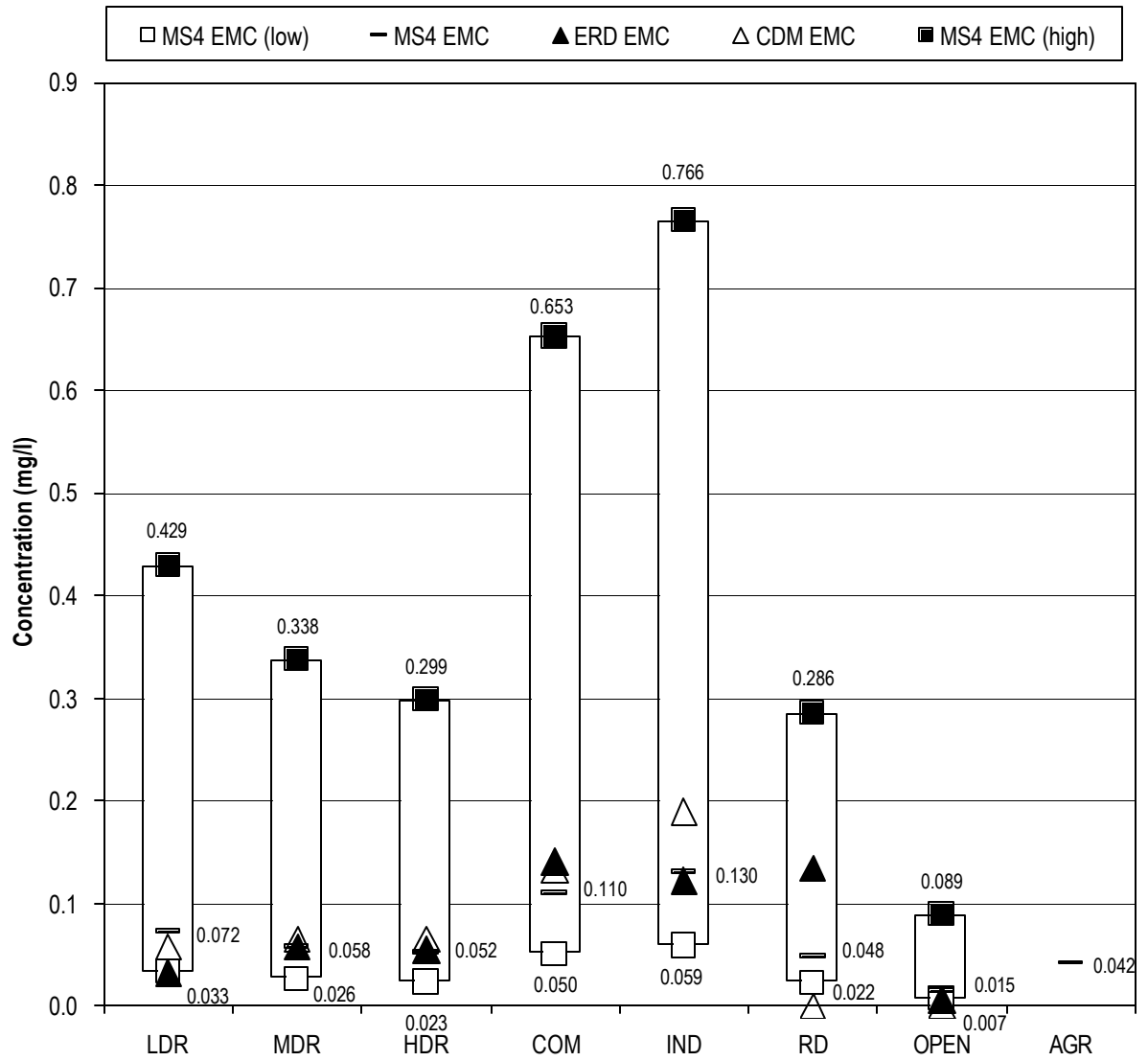
Best Management Practices Pollutant Removal Efficiency

BMP removal efficiencies for a list of potential practices were collected from two sources: *Monroe County Stormwater Management Plan* by CDM and *Pollutant Removal Efficiencies for Typical Stormwater Management Systems in Florida* by ERD.

Runoff Coefficients

Runoff coefficients for different land uses were collected from the *Monroe County Stormwater Management Plan* by CDM and *Stormwater Loading Rates for Central and South Florida* by ERD.

The original intent of the DO 8 scope was to develop a set of rules for estimating BMP performance in the Keys that is based upon literature values for specific BMPs and documented performance of existing BMPs that have been implemented in the Keys. Unfortunately, there are very few actual stormwater BMPs in use in the Keys and we have found no documentation of actual performance for the few BMPs that have been implemented in the Study Area. Consequently, no basis exists for developing CCAM rules for adjusting BMP treatment levels.

3.3.3 Revised Component Formulation

The previous identification of variables for the Stormwater Component was based on a conceptual approach and assumed that all possible data existed. In the pursuit of available data, it was found that a number of different variables could not be addressed given the proposed time scale and the lack of sufficient or adequate data to describe and characterize the variable. In some cases, additional variables were developed and added, such as the wet/dry precipitation and low/high EMC variables.

The washoff model concept used in the Stormwater Component applies a land use defined pollutant loading rate (EMC) combined with a computed runoff volume to estimate the total pollutant load. This is the model used extensively throughout Florida, is recognized by FDEP, and was the computational method used in the stormwater master plans developed and adopted by Monroe County, the Village of Islamorada, and the City of Key Colony Beach.

The input and output variables incorporated in the revised Stormwater Component are defined in the following paragraphs.

Input Variables

- CATCH [*n*] = Catchment number (delineated drainage area) is the first aggregation unit for development of runoff volumes and pollutant loads. Each catchment (*n*) is a sub-portion of a wastewater planning unit/island. CATCH [*n*] is an internal variable used by the GIS system.

- PRECIPAVG [*t, pu*] = The average rainfall in decimal inches for period (*t*) at wastewater planning unit (*pu*) (output from the Weather Component).

- PRECIPWET [*t, pu*] = The wet period (90-percentile non-exceedance) rainfall in decimal inches for period (*t*) at wastewater planning unit (*pu*). Rainfall for period (*t*) will exceed this value no more than 10 percent of the time (output from the Weather Component).

- PRECIPDRY [*t, pu*] = The dry period (10-percentile non-exceedance) rainfall in decimal inches for period (*t*) at wastewater planning unit (*pu*). Rainfall for period (*t*) will be less than this value no more than 10 percent of the time (output from the Weather Component).

- LU [*n, z, a*] = Land use data array of the aggregated area (*a*) of each land use within catchment (*n*) by Florida Land Use Classification Code System (FLUCCS) codes (*z*).

- IMPBMP [*x, n ,tt, a*] = BMP data array with (*x*) different implemented practices, each identified by type (*tt*) and the area (*a*) that it serves within catchment (*n*).

Input Constants

- RCLUC [*z, c, luc*] = Data table of FLUCCS codes (*z*), the associated runoff coefficient (*c*) and the associated land use code (*luc*). The runoff coefficient (*c*) ranges from 0 to 1 and controls the volume of runoff generated by rainfall. The land use code (*luc*) aggregates the hundreds of different FLUCCS codes to a few general land use values for the assignment of EMCs.

- EMCAVG [*luc, y*] = Data table of average EMCs for pollutant (*y*), measured in mg/l, of stormwater runoff from land use (*luc*).

- EMCLO [*luc ,y*] = Data table of the 10-percentile non-exceedance EMCs for pollutant (*y*), measured in mg/l, of stormwater runoff from land use (luc). No more than 10 percent of the observed storm EMCs should be less than this value.

- EMCHI [*luc ,y*] = Data table of the 90-percentile non-exceedance EMCs for pollutant (*y*), measured in mg/l, of stormwater runoff from land use *(luc)*. No more than 10 percent of the observed storm EMCs should be greater than this value.

- BMP [*tt, r, y*] = Data table of BMPs identified by type (*tt - an integer index value*) and the typical removal efficiency (*r - expressed as a %*) for pollutant (*y*).

Output Variables

- SWLOADAVG [*n, t, y, avg, wet, dry*] = the average expected pollutant load (decimal pounds) of pollutant (*y*) in the stormwater runoff from catchment (*n*) over the average, wet and dry period (*t*).

- SWLOADLO [*n, t, y, avg, wet, dry*] = the 10-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) in the stormwater runoff from catchment (*n*) over the average, wet and dry period (*t*).

- SWLOADHI [*n, t, y, avg, wet, dry*] = the 90-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) in the stormwater runoff from catchment (*n*) over the average, wet and dry period (*t*).

- BMPLOADAVG [*n, t, y, avg, wet, dry*] = the average expected pollutant load (decimal pounds) of pollutant (*y*) removed from stormwater runoff from catchment (*n*) over the average, wet and dry period (*t*).

- BMPLOADLO [*n, t, y, avg, wet, dry*] = the 10-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) removed from stormwater runoff from catchment (*n*) over the average, wet and dry period (*t*).

- BMPLOADHI [*n, t, y, avg, wet, dry*] = the 90-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) removed from stormwater runoff from catchment (*n*) over the average, wet and dry period (*t*).

- SWLOAD2HZAVG [*n, t, y, avg, wet, dry*] = the average expected pollutant load (decimal pounds) of pollutant (*y*) discharged from catchment (*n*) to the Immediate Nearshore Waters Component over the average, wet and dry period (*t*).

- SWLOAD2HZLO [*n, t, y, avg, wet, dry*] = the 10-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) discharged from catchment (*n*) to the Immediate Nearshore Waters Component over the average, wet and dry period (*t*).

- SWLOAD2HZHI [*n, t, y, avg, wet, dry*] = the 90-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) discharged from catchment (*n*) to the Immediate Nearshore Waters Component over the average, wet and dry period (*t*).

- SWVOL2HZ [*n, t, vavg, vwet, vdry*] = the volume (acre-feet) of stormwater discharged from catchment (*n*) to the Immediate Nearshore Waters Component over the average, wet and dry period (*t*).

- SWLOAD2GWAVG [*n, t, y, avg, wet, dry*] = the average expected pollutant load (decimal pounds) of pollutant (*y*) discharged from catchment (*n*) to the Groundwater Component over the average, wet and dry period (*t*).

- SWLOAD2GWLO [*n, t, y, avg, wet, dry*] = the10-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) discharged from catchment (*n*) to the Groundwater Component over the average, wet and dry period (*t*).

- SWLOAD2GWHI [*n, t, y, avg, wet, dry*] = the 90-percentile non-exceedance pollutant load (decimal pounds) of pollutant (*y*) discharged from catchment (*n*) to the Groundwater Component over the average, wet and dry period (*t*).

- SWVOL2GW [*n, t, vavg, vwet, vdry*] = the volume (acre-feet) of stormwater from catchment (*n*) to the Groundwater Component over the average, wet and dry period (*t*).

Rules for Adjustments of BMP Treatment

The original intent of the scope of work for this report was to develop a set of rules for estimating BMP performance in the Keys that are based upon literature values for specific BMPs and documented performance of existing BMPs that have been implemented in the Keys. Unfortunately, there are very few actual stormwater BMPs in use in the Keys and the Contractor has found no documentation of actual performance for the few BMPs that have been implemented in the Study Area. Consequently, no basis exists for developing CCAM rules for adjusting BMP treatment levels.

3.3.4 Enabling Assumptions

A number of enabling assumptions were made to allow the development of the Stormwater Component given the size of the modeled system, the time spans being modeled, and the level of output detail. These assumptions included the following:

- Use of a limited number of generic land uses (currently 10) to characterize variations in EMCs,
- Runoff coefficients based on land use rather than unique parcel- or watershed-based measurements,
- Pollutant load predictions based on the washoff model concept,
- BMPs and literature efficiencies that apply in the Keys, and
- EMCs from MS4 data are representative of Keys runoff.

The last enabling assumption is based upon the consideration that while no specific EMC data exists for the Keys, the Keys are similar to many of the coastal communities from which the exclusive Florida-based MS4 data (developed by the Contractor) is taken. The Florida-based MS4 data are similar to the Keys in the following respects:

- Coastal communities,
- Minimal topographic relief,
- Similar types of land uses,
- Comparable exposure to atmospheric deposition, and
- Similar normal weather patterns.

Recognizing that there are significant differences in runoff/infiltration regimes and subsurface conditions, the Florida MS4s EMC values represent the best available data for use in the Stormwater Component. At some future date, when Keys-based EMC values become available, they can be directly inserted into the algorithm.

3.3.5   Current Computational Algorithm

The computational algorithm for the Stormwater Component consists of six specific elements. Each of these elements is described in this section.

Runoff Volume

Runoff volumes are computed for each entry in the LU [n, z, a] data array. Each entry in LU [n, z] is a sub-element of catchment (n) composed of a single FLUCCS code (z). Runoff volume is based on the rainfall for time period (t), the runoff coefficient (c) and the area (a) associated with the land use (z).

There are three rainfall volumes considered for time period (t): the average period, the wet (90 percent non-exceedance) period and the dry (10 percent non-exceedance) period. The rainfall values are inputs from the Weather Component using the rainfall variables PRECIPAVG [t, pu], PRECIPWET [t, pu], and PRECIPDRY [t, pu]. The time period value (t) is a user input and the wastewater planning unit value (pu) is determined by the GIS system based on the location of the drainage basin (n).

The runoff coefficient (c) is based on land use (z) for the sub-element. RCLUC [z, c, luc] is a data table that holds both the runoff coefficient (c) and the aggregated land use code (luc) used for assigning pollutant EMC values. The data table is indexed by the FLUCCS code (z) allowing each entry in the LU [n, z, a] data array to be expanded to include the appropriate runoff coefficient (c) and land use code (luc) based on the FLUCCS code (z) value.

Once the LU [n, z, a, c, luc] data array has been updated to include the runoff coefficient (c), the runoff volumes can be computed for each entry. Volumes are computed using each of the three rainfall values to represent the runoff for the average (vavg), wet (vwet), and dry (vdry) conditions. These are based on expected meteorological conditions such as a wet or dry year and not antecedent moisture conditions. It should be noted that rainfall occurs in discrete events, some of which are insufficient to generate any runoff. The volume of these small rainfall events should be deducted from the total rainfall volume to better reflect the actual rainfall volume expected. Analysis of rainfall from 15-minute and hourly records for stations around Florida have identified that approximately 2 to 5 percent of the rainfall occurs in events of less than 0.10 inches and are assumed to produce no runoff. A rainfall-runoff correction factor of 98 percent is applied to the rainfall volumes to adjust for this phenomenon. Runoff volumes are computed using the following formula:

$$V = (1/12) * 0.98 * PRECIP * RC * AREA$$

Where: V is the volume (acre-feet)
(1/12) is a conversion factor from inches to feet
0.98 is the rainfall-runoff conversion factor
PRECIP is the rainfall in inches for the time period (t) and wastewater planning unit (pu)
RC is the runoff coefficient (c)
AREA is the area of the sub-element (acres)

Runoff volumes for each of the three conditions (average, wet, and dry) are then developed for each catchment (*n*) by summing the individual sub-elements. These values are stored in the output variable SWVOL2HZ [*n, t, vavg, vwet, vdry*].

Stormwater Pollutant Load

Pollutant load is computed for each sub-element in a similar fashion using the land use code (*luc*) to set the EMC values, which are then applied to the runoff volumes to determine the pollutant contribution. The EMC values are kept in three data tables: the average concentration, the low (10-percentile non-exceedance) concentration and the high (90-percentile non-exceedance) concentration. The EMC data tables have an entry for each of the pollutants in the model (*y*) and are associated with the LU [*n, z, a*] data array through the assigned land use code (*luc*) from the RCLUC[*z, c, luc*] data table as discussed previously. This links the EMC values for each pollutant (*y*) with each entry in the LU data array. The pollutant load is computed using the following formula:

$$\text{SWLOAD} = \text{EMC} * V * 43560 * 28.317 * 10^{-6} * 2.205$$

Where: SWLOAD is the pollutant load (pounds)
EMC is the event mean concentration (mg/l)
V is the runoff volume (acre-feet)
43560 converts acre-feet to cubic feet
28.317 converts cubic feet to liters
10^{-6} converts mg to kg
2.205 converts kg to pounds

These values are computed for each of the three EMC data tables. Pollutant load for each EMC (average, 10-percentile and 90-percentil) and each of the three conditions (average, wet and dry) are developed for each catchment (*n*) by summing the individual sub-elements. The resulting total load is stored in the appropriate output variables: SWLOADAVG [*n, t, y, avg , wet, dry*], SWLOADLO [*n, t, y, avg , wet, dry*] and SWLOADHI [*n, t, y, avg , wet, dry*] for each pollutant (*y*).

BMP Load Reduction

Pollutant load reduction is developed using the information from the IMPBMP[*x, n, tt, a*] data array, which describes the BMPs implemented within each drainage area, and the data table BMP [*tt, r, y*], which describes the performance of each BMP for each pollutant. Multiple BMPs (from 0 to x) can be implemented within each catchment (n). Removal is computed by linking the removal efficiency (*r*) for each pollutant (*y*) from the BMP table to each entry in the IMPBMP data array based on the treatment type (*tt*). The total area of each catchment (n) is computed by summing the sub-elements in the LU [*n, z, a*] data array. Pollutant load reduction is computed using the following formula:

BMPLOAD = SWLOAD * RR * a / A

> Where: BMPLOAD is the pollutant load reduction (pounds)
> SWLOAD is the total pollutant load (pounds)
> RR is the removal rate (r) for the pollutant (y) (%)
> a is the area associated with the BMP (acres)
> A is the total area of catchment (n) in acres

These values are computed for each pollutant in each of the three SWLOAD output variables. These values are summed for each entry in the IMPBMP data array to develop the total load removed by all implemented BMPs for each pollutant (y) in each catchment (n). The results are stored in the appropriate output variables: BMPLOADAVG [*n, t, y, avg, wet, dry*], BMPLOADLO [*n, t, y, avg , wet, dry*], and BMPLOADHI [*n, t, y, avg, wet, dry*].

Discharged Stormwater Pollutant Load

The difference between the SWLOAD and the BMPLOAD variables is the load assumed to be discharged to the immediate nearshore waters. Thus the output variables SWLOAD2HZAVG [*n, t, y, avg , wet, dry*], SWLOAD2HZLO [*n, t, y, avg , wet, dry*] and SWLOAD2HZHI [*n, t, y, avg , wet, dry*] are computed using the following formula:

> SWLOAD2HZ = SWLOAD - BMPLOAD

> Where: SWLOAD2HZ is the pollutant load to the immediate nearshore waters
> (pounds)
> SWLOAD is the total pollutant load (pounds)

Groundwater Recharge Volume

Groundwater recharge volumes are computed as a portion of rainfall. The Groundwater Component (see Section 3.5.1) includes a paper by M.J. Wightman that estimated the recharge to be approximately 20 percent of rainfall. This portion (20 percent) is assumed to be based on recharge from pervious areas only and impervious areas would not contribute to recharge. Pervious area can be estimated from the runoff coefficient (c), previously stored in the LU [*n, z, a, c, luc*] data array during the calculation of stormwater runoff volumes.

The runoff coefficient is a composite value that represents both the pervious and impervious areas. Runoff from impervious areas is commonly assumed to equal 90 percent of the rainfall quantity. Conversely, runoff from pervious areas is commonly assumed to equal 20 percent of the rainfall quantity. The runoff values of 90 percent for impervious areas and 20 percent for pervious areas are within the range of values typically applied by the rational method for the computation of runoff. These specific values were used in the *Monroe County Stormwater Management Master Plan* and subsequently adopted for use in the CCAM.

The runoff coefficient is an area weighted average of the pervious and impervious areas. Manipulating the weighted average computation allows the pervious area (*ap*) to be computed for each element, expanding the data array to LU [*n, z, a, c, luc, ap*] using the following formula:

$$ap = [(c * a) - (CI * a)] / (CP - CI)$$

Where: *ap* is the pervious area for the land use element (acres)
          c is the runoff coefficient for the land use element
          a is the area of the land use element (acres)
          CI is the impervious area rainfall-runoff ratio (0.90)
          CP is the pervious area rainfall-runoff ratio (0.20)

Recharge volumes for each of the three conditions (average, wet, and dry) are then developed for each catchment (*n*) by summing the pervious area (*ap*) of the individual sub-elements within the catchment and applying the following formula:

$$SWVOL2GW = 1/12 * AP * PRECIP * 0.20$$

Where: SWVOL2GW is the recharge volume (acre-feet)
          (1/12) is a conversion factor from inches to feet
          AP is total pervious area for catchment (*n*) (acres)
          PRECIP is the rainfall in inches for time period (*t*) and wastewater
          planning unit (*pu*)
          0.20 is the fraction of rainfall resulting in recharge

The 20 percent used in this formula should not be confused with the 20 percent runoff coefficient for pervious areas. Not all of the water that doesn't run off (80 percent) becomes a contribution to groundwater. Some remains in void spaces in the soil/sand, some is transpired by vegetation and some is evaporated back to the atmosphere. Earlier studies estimated that only 20 percent of the rainfall on pervious areas becomes groundwater in the Keys. A volume is calculated for each of the three conditions (average, wet and dry) and the values are stored in the output variable SWVOL2GW [*n, t, vavg, vwet, vdry*].

Groundwater Recharge Pollutant Load

Pollutant load is computed for each sub-element in a similar method as used for the stormwater loads. The pollutant load is computed using the following formula:

$$SWLOAD2GW = EMC * SWVOL2GW * 43560 * 28.317 * 10^{-6} * 2.205$$

Where: SWLOAD2GW is the pollutant load (pounds)
          EMC is the event mean concentration (mg/l)
          SWVOL2GW is the recharge volume (acre-feet)
          43560 converts acre-feet to cubic feet
          28.317 converts cubic feet to liters
          10^{-6} converts mg to kg
          2.205 converts kg to pounds

These values are computed for each of the three EMC data tables. Pollutant load for each EMC (average, 10-percentile and 90-percentile) and each of the three conditions (average, wet and dry) are developed for each catchment (n) by summing the individual sub-elements. The resulting total load is stored in the appropriate output variables: SWLOAD2GWAVG [*n, t, y, avg, wet, dry*], SWLOAD2GWLO [*n, t, y, avg , wet, dry*] and SWLOAD2GWHI [*n, t, y, avg , wet, dry*] for each pollutant (*y*).

3.3.6   Definition of Datasets

With the revised model formulation, the following representative datasets were needed to support the current model algorithms:

- EMC values by land use,
- Runoff coefficients by land use,
- Catchment delineations, and
- BMP efficiencies.

EMC Values

EMC values were taken from three different sources: Florida MS4 communities, the *Monroe County Stormwater Management Master Plan*, and the Environmental Research & Design report *Stormwater Loading Rate Parameters for Central and South Florida*. The pollutants incorporated into the Stormwater Component were based on those for which data were available. These included the following parameters:

- Total Nitrogen (TN),
- Total Kjeldahl Nitrogen (TKN),
- Nitrite plus Nitrate ($NO_2 + NO_3$, or NO_X),
- Total Phosphorous (TP),
- Ortho-Phosphorous or Total Dissolved Phosphorous (TDP),
- Biochemical Oxygen Demand (BOD),
- Chemical Oxygen Demand (COD),
- Total Suspended Solids (TSS),
- Total Dissolved Solids (TDS),
- Cadmium (Cd),
- Copper (Cu),
- Lead (Pb), and
- Zinc (Zn).

The land use codes (LUC) were based on the land use characterization available from the EMC data. The land use codes used to characterize EMCs are as follows:

- Low Density Residential (LDR),
- Medium Density Residential (MDR),
- High Density Residential (HDR),
- Commercial (COM),
- Industrial (IND),
- Roadways (RD),
- Open Space (OPEN),
- Agriculture (AGR),
- Wetlands (WL), and
- Open Water (OW).

In most cases, the MS4 data was adopted for use in the model since it was considered to be the most recent and allowed for the development of uncertainty analysis (use of the 10-percentile and 90-percentile values). The exceptions to the adoption of the MS4 data included: agriculture (AGR), wetlands (WL) and open water (OW) since little or no data were collected for these land uses by the MS4 communities. These values were adopted from the data presented in the *Monroe County Stormwater Master Plan* and the Environmental Research & Design Report. Table 16 presents the selected EMC values selected for use in the model. These values are stored in the three input constants: EMCAVG [*luc, y*], EMCLO [*luc, y*], and EMCHI [*luc, y*].

TABLE 16
SELECTED EMC VALUES

Parameter	EMC (mg/l)	10% EMC (mg/l)	90% EMC (mg/l)	EMC (mg/l)	10% EMC (mg/l)	90% EMC (mg/l)
LAND USE:	**LDR**			**MDR**		
TN	2.95	1.35	17.53	1.62	0.71	9.20
TKN	2.36	1.08	13.96	1.26	0.56	7.28
$NO_2 + NO_3$	1.03	0.44	5.77	0.30	0.13	1.72
TP	0.39	0.17	2.27	0.46	0.20	2.64
OP	0.21	0.10	1.25	0.25	0.11	1.43
BOD	9	4	54	12	5	71
COD	74	32	415	54	23	302
TSS	35	16	206	32	14	188
TDS	134	61	794	92	40	525
Cd	0.0029	0.0013	0.0171	0.0013	0.0006	0.0073
Cu	0.0185	0.0084	0.1092	0.0219	0.0100	0.1294
Pb	0.0166	0.0076	0.0981	0.0157	0.0069	0.0898
Zn	0.0723	0.0331	0.4295	0.0580	0.0260	0.3375
LAND USE:	**HDR**			**COM**		
TN	2.09	0.95	12.34	2.04	0.93	12.02
TKN	1.29	0.57	7.44	1.55	0.70	9.13

TABLE 16
(Continued)
SELECTED EMC VALUES

Parameter	EMC (mg/l)	10% EMC (mg/l)	90% EMC (mg/l)	EMC (mg/l)	10% EMC (mg/l)	90% EMC (mg/l)
$NO_2 + NO_3$	0.89	0.39	5.07	0.66	0.29	3.80
TP	0.32	0.14	1.88	0.32	0.15	1.92
OP	0.19	0.09	1.11	0.17	0.08	1.03
BOD	15	6	79	25	9	123
COD	69	32	410	87	39	508
TSS	23	10	135	57	26	332
TDS	287	103	1,336	233	95	1,239
Cd	0.0019	0.0008	0.0106	0.0033	0.0015	0.0195
Cu	0.0639	0.0229	0.2966	0.0193	0.0088	0.1141
Pb	0.0111	0.0049	0.0633	0.0181	0.0080	0.1039
Zn	0.0522	0.0230	0.2985	0.1100	0.0503	0.6531
LAND USE:	**IND**			**RD**		
TN	2.89	1.32	17.12	1.44	0.57	7.45
TKN	1.32	0.57	7.38	1.46	0.61	7.96
$NO_2 + NO_3$	0.80	0.34	4.38	0.26	0.12	1.51
TP	0.44	0.20	2.57	0.26	0.12	1.57
OP	0.22	0.10	1.30	0.08	0.03	0.45
BOD	11	5	61	8	4	49
COD	67	29	379	77	33	425
TSS	68	30	396	40	18	239
TDS	172	79	1,020	132	59	766
Cd	0.0071	0.0027	0.0355	0.0016	0.0007	0.0088
Cu	0.0765	0.0253	0.3285	0.0170	0.0069	0.0895
Pb	0.0621	0.0261	0.3392	0.0250	0.0069	0.0901
Zn	0.1302	0.0590	0.7658	0.0482	0.0220	0.2856
LAND USE:	**OPEN**			**AGR**		
TN	1.48	0.57	7.44	2.32		
TKN	1.29	0.49	6.38	1.74		
$NO_2 + NO_3$	0.15	0.07	0.87	0.58		
TP	0.34	0.15	1.99	0.34		
OP	0.22	0.10	1.26	0.23		
BOD	11	5	67	4		
COD	80	37	474	51		
TSS	31	14	182	55		
TDS	118	50	651	100		
Cd	0.0033	0.0015	0.0189			
Cu	0.0115	0.0051	0.0657			
Pb	0.0110	0.0050	0.0643			
Zn	0.0150	0.0069	0.0890			
LAND USE:	**WL**			**OW**		
TN	1.6			1.25		
TKN	1.2			0.9375		
$NO_2 + NO_3$	0.4			0.3125		
TP	0.19			0.11		
OP	0.13			0.05		
BOD	4.63			1.6		

TABLE 16
(Continued)
SELECTED EMC VALUES

Parameter	EMC (mg/l)	10% EMC (mg/l)	90% EMC (mg/l)	EMC (mg/l)	10% EMC (mg/l)	90% EMC (mg/l)
COD	6			6		
TSS	10.2			3.1		
TDS	12			12		
Cd	0.001			0.001		
Cu	0.007			0.007		
Pb	0.011			0.011		
Zn	0.006			0.028		

Runoff Coefficients and Land Use Codes

Runoff coefficients were presented for the generic land use codes in the ERD report. The *Monroe County Stormwater Management Master Plan* computed runoff using estimated values for impervious area and then computing runoff based on coefficients of 0.95 for impervious area and 0.20 for pervious area. The runoff coefficients were adopted from the ERD report for implementation in the Stormwater Component. These were assigned by FLUCCS code rather than by LUC to allow better definition of runoff from a greater variation in land use. Each FLUCCS code was also assigned a LUC codes to link the EMC values. LUC codes are used to describe the pollutant characteristic of a land use, while FLUCCS codes are used to describe the runoff potential. Table 17 presents the list of FLUCCS codes with the corresponding runoff coefficient (c) and land use code (LUC).

TABLE 17
FLUCCS CODES, LAND USE CODES AND RUNOFF COEFFICIENTS

FLUCCS	Description	LUC	Runoff Coeff.
100	**Urban and Built Up**		
110	**Residential - Low Density (<2 per acre)**	LDR	0.268
111	Fixed Single-Family Units	LDR	0.268
112	Mobile Home Units	LDR	0.268
113	Mixed Units (Fixed and Mobile)	LDR	0.268
120	**Residential - Medium Density (2-5 per acre)**	MDR	0.373
121	Fixed Single-Family Units	MDR	0.373
122	Mobile Home Units	MDR	0.373
123	Mixed Units (Fixed & Mobile)	MDR	0.373
129	Medium Density Under Construction	MDR	0.373
130	**Residential - Medium Density (6+ per acre)**	HDR	0.675
131	Fixed Single-Family Units	HDR	0.675
132	Mobile Home Units	HDR	0.675
133	Multiple Dwelling Units, Low Rise	HDR	0.675
134	Multiple Dwelling Units, High Rise	HDR	0.675
139	High Density Under Construction	HDR	0.675

FLUCCS	Description	LUC	Runoff Coeff.
140	**Commercial and Services**	COM	0.887
141	Retail Sales	COM	0.887
142	Wholesale Sales	COM	0.887
143	Professional Services	COM	0.887
144	Cultural & Entertainment	COM	0.887
145	Tourist Services	COM	0.887
147	Mixed Commercial & Services	COM	0.887
148	Cemeteries	OPEN	0.163
149	Commercial & Services Under Construction	COM	0.793
150	**Industrial**	IND	0.793
154	Oil & Gas Processing	IND	0.793
155	Other Light Industrial	IND	0.793
156	Other Heavy Industrial	IND	0.793
160	**Extractive**	IND	0.361
161	Strip Mines	IND	0.361
162	Sand & Gravel Pits	IND	0.361
170	**Institutional**	COM	0.837
171	Educational Facilities	COM	0.837
172	Religious	COM	0.837
173	Military	COM	0.837
174	Medical & Health Care	COM	0.837
175	Governmental	COM	0.837
176	Correctional	COM	0.837
177	Other Institutional	COM	0.837
178	Commercial Child Care	COM	0.837
180	**Recreational**	OPEN	0.163
181	Swimming Beach	OPEN	0.163
182	Golf Courses	OPEN	0.163
185	Parks & Zoos	OPEN	0.163
186	Community Recreational Facilities	OPEN	0.163
188	Historical Sites	OPEN	0.163
189	Other Recreational	OPEN	0.163
190	**Open Land**	OPEN	0.163
191	Undeveloped Land in Urban Areas	OPEN	0.163
192	Inactive with Streets & No Structures	LDR	0.268
193	Urban Land in Transition	OPEN	0.163
200	**AGRICULTURE**	AGR	0.304
210	**Cropland & Pastureland**	AGR	0.355
211	Improved Pastures	AGR	0.355
212	Unimproved Pastures	AGR	0.355
214	Row Crops	AGR	0.204
220	**Tree Crops**	AGR	0.282
223	Other Groves	AGR	0.282
230	**Feeding Operations**	AGR	0.304
232	Poultry Feeding Operations	AGR	0.304
240	**Nurseries & Vineyards**	AGR	0.304

FLUCCS	Description	LUC	Runoff Coeff.
243	Ornamentals	AGR	0.304
250	**Specialty Farms**	AGR	0.304
252	Dairies	AGR	0.304
254	Aquaculture	OW	0.500
260	**Other Open Lands (rural)**	OPEN	0.163
300	**RANGELAND**	OPEN	0.163
320	**Shrub and Brushland**	OPEN	0.163
400	**UPLAND FORESTS**	OPEN	0.163
410	**Upland Coniferous Forest**	OPEN	0.163
411	Pine Flatwoods	OPEN	0.163
412	Longleaf Pine	OPEN	0.163
413	Sand Pine	OPEN	0.163
414	Pine	OPEN	0.163
415		OPEN	0.163
416		OPEN	0.163
419	Other Pines	OPEN	0.163
420	**Upland Hardwood Forest**	OPEN	0.163
421	Xeric Oak	OPEN	0.163
427	Live Oak	OPEN	0.163
429	Wax Myrtle	OPEN	0.163
430	**Upland Hardwood Forest (cont)**	OPEN	0.163
431	Beech - Magnolia	OPEN	0.163
434	Hardwood - Conifer Mixed	OPEN	0.163
436		OPEN	0.163
438	Mixed Hardwoods	OPEN	0.163
439	Other Hardwoods	OPEN	0.163
440	**Tree Plantations**	OPEN	0.163
441	Coniferous Plantations	OPEN	0.163
443	Forest Regeneration Areas	OPEN	0.163
461		OPEN	0.163
500	**WATER**	OW	0.500
510	**Streams & Waterways**	OW	0.500
520	**Lakes**	OW	0.500
521	Lakes > 500 acres	OW	0.500
522	Lakes (> 100 acres and < 500 acres)	OW	0.500
523	Lakes (> 10 acres and < 100 acres)	OW	0.500
524	Lakes < 10 acres	OW	0.500
525		OW	0.500
530	**Reservoirs**	OW	0.500
550	**Major Springs**	OW	0.500
600	**WETLANDS**	WL	0.225
610	**Wetland Hardwood Forests**	WL	0.225
611	Bay Swamps	WL	0.225
613	Gum Swamps	WL	0.225
614	Titi Swamps	WL	0.225
615	Stream and Lake Swamps	WL	0.225

FLUCCS	Description	LUC	Runoff Coeff.
616	Inland Ponds & Sloughs	WL	0.225
618		WL	0.225
619		WL	0.225
620	**Wetland Coniferous Forests**	WL	0.225
621	Cypress	WL	0.225
623	Atlantic White Cedar	WL	0.225
630	**Wetland Forest Mixed**	WL	0.225
631		WL	0.225
640	**Vegetated Non-Forested Wetlands**	WL	0.225
641	Freshwater Marshes	WL	0.225
643	Wet Prairies	WL	0.225
644	Emergent Aquatic Vegetation	WL	0.225
645	Submergent Aquatic Vegetation	WL	0.225
650	**Non-Vegetated**	WL	0.225
653	Intermittent Ponds	WL	0.225
700	**Barren Land**	OPEN	0.163
740	**Disturbed Land**	OPEN	0.163
741	Rural Land in Transition	OPEN	0.163
800	**Transportation, Communication & Utilities**	IND	0.793
810	**Transportation**	RD	0.783
811	Airports	RD	0.783
812	Railroads	RD	0.783
814	Roads & Highways	RD	0.783
817	Oil, Water or Gas Transmission Lines	OPEN	0.163
820	**Communications**	COM	0.837
822	Communication Facilities	COM	0.837
830	**Utilities**	IND	0.783
831	Electrical Power Facilities	IND	0.783
833	Water Supply Plants	IND	0.783
834	Sewage Treatment	IND	0.783
835	Solid Waste Disposal	IND	0.783
900	**Special Classifications***	--	

* No parcels included in this category

BMP Efficiencies

Pollutant removal rates, expressed in terms of the percentage of load removed, were adopted from the *Monroe County Stormwater Management Master Plan*. Table 18 presents the list of selected BMPs and their corresponding pollutant removal rates (r), for each of the modeled pollutant parameters (y).

TABLE 18

POLLUTANT REMOVAL RATES FOR SELECTED BMPs

BMP	Description	Removal Rates (% Reduction)				
		TN	TKN	NO$_X$	TP	OP
1	Extended Dry Detention	10	15	0	25	0
2	Wet Detention	30	35	25	45	65
3	Retention	95	95	95	95	95
4	Swales	20	30	15	40	15
5	Retention Swales with Wet Detention	74	72	76	80	88
6	Bioretention		74		77	
7	Water Quality Inlets and Baffle Boxes	5	0	5	35	0
8	Infiltration Drainfields	83			65	
9	Modular Treatment System (StormTreat®)	77			90	
10	Porous Pavement	83			65	
11	Sand Filters	21	46	0	33	
12	Stormwater Wetlands	28			49	
13	Alum Treatment	50			90	

BMP	Description	Removal Rates (% Reduction)				
		BOD	COD	TSS	TDS	Cd
1	Extended Dry Detention	25	25	85	0	75
2	Wet Detention	30	30	85	30	75
3	Retention	95	95	95	95	95
4	Swales	30	30	80	10	65
5	Retention Swales with Wet Detention	76	76	96	76	92
6	Bioretention			90		
7	Water Quality Inlets and Baffle Boxes	25	25	80	0	60
8	Infiltration Drainfields			89		
9	Modular Treatment System (StormTreat®)		82	99		
10	Porous Pavement			89		
11	Sand Filters	70		70		
12	Stormwater Wetlands			67		36
13	Alum Treatment	75		90		

BMP	Description	Removal Rates (% Reduction)		
		Cu	Pb	Zn
1	Extended Dry Detention	55	75	35
2	Wet Detention	65	75	45
3	Retention	95	95	95
4	Swales	50	75	45
5	Retention Swales with Wet Detention	88	92	80
6	Bioretention	96	96	96
7	Water Quality Inlets and Baffle Boxes	50	73	35
8	Infiltration Drainfields			
9	Modular Treatment System (StormTreat®)		77	90
10	Porous Pavement			
11	Sand Filters		45	45
12	Stormwater Wetlands	41	62	45
13	Alum Treatment	80	90	80

Source: *Monroe County Stormwater Management Master Plan*.

The CCAM uses BMP efficiency values from the recently adopted *Monroe County Stormwater Master Plan* (Table 16). However, actual BMP efficiencies may be different in the Keys due to their unique subsurface geology and surface drainage conditions. Should pollutant removal performance data be collected for BMPs installed in the Keys, the values used in the Stormwater Component can be readily adjusted to reflect the new data.

<u>Catchment Delineations</u>

Runoff catchments were delineated from aerial photography. Due to the lack of natural topographic relief throughout the Keys, delineations were made based on roadways, which tend to form artificial but effective drainage divides and delineate similar land use covers. These delineations were made directly in GIS with the delineation lines connected to the existing shoreline coverage for accuracy. These delineations form the basis for the first aggregation of runoff quantities and qualities for discharge to the receiving water/groundwater. Each catchment area is associated with the wastewater planning unit/island in which it lies. This association forms the basis for the linkage with the Weather Component for rainfall volumes.

3.3.7   Integration Considerations

There are no known integration considerations that would require manipulation to overcome obstacles in the Stormwater Component.

3.4   Wastewater Component

The pollutant loads resulting from wastewater treatment and disposal practices are an important component of the ambient water quality conditions in the waters in the Study Area and constitute an indirect impact on the carrying capacity of the Florida Keys, with respect to the degradation of water quality and health of the marine environment.

3.4.1   Ancillary Investigation Activities

The Wastewater Component utilizes available water use estimates from the Potable Water Demand Component, parcel ownerships, mapping and datasets, wastewater generation estimates, wastewater characteristics per treatment method and discharge/disposal method data from the contributing wastesheds to estimate pollutant loads discharged to groundwater systems and thence discharged to the receiving surface water. A summary of the information that was investigated and obtained to support the development of the Wastewater Component is provided in Table 19.

TABLE 19

LIST OF INFORMATION RECEIVED BY SOURCE

Information/Document	Source
Inventory of wastewater treatment plants, method of treatment, type effluent disposal, and location of point(s) of discharge	Monroe County Sanitary Wastewater Master Plan (CH2MHILL, 2000)
Representative wastewater effluent concentrations based on treatment method	Monroe County Sanitary Wastewater Master Plan (CH2MHILL, 2000)
Parcel database in GIS format for entire Keys	Monroe County Sanitary Wastewater Master Plan (CH2MHILL, 2000)
Wastewater Facilities Plan for Marathon	Monroe County (June, 1998)
Updated list of permitted wastewater treatment plants in the Keys	Florida Department of Environmental Protection (March, 2000)
Existing and Pending Regulations	Florida Law, Florida Administrative Code
Impact of Wastewater Discharges from Tourist Resorts on Eutrophication in Coral Reef Regions and Recommended Methods of Treatment	Proceedings of the 1990 Congress on Coastal and Marine Tourism, Honolulu, HI (May, 1990)
Assessment of Florida On-Site Disposal System Regulations for the Removal of Viruses	University of South Florida, Department of Marine Science, St. Petersburg, FL (May, 1998)

The *Monroe County Sanitary Wastewater Master Plan* (CH2MHILL, 2000) is an eight-volume master plan that includes a partially completed database of wastewater sources within the Keys. It identifies areas of water quality concern related to wastewater discharges, evaluates suitable treatment and effluent technologies, and defines a long-term implementation plan intended to improve wastewater treatment practices in the Keys and improve water quality. Data utilized from this plan in development of the Wastewater Component include:

- Estimate of the number of on-site wastewater systems [septic systems, cesspools, aerated treatment units (ATU), and sub-standard septic systems].

- Wastewater generation rates per equivalent dwelling unit (EDU), which varies per wastewater study area.

- Typical treated wastewater concentrations based on treatment technology

- Inventory of FDEP permitted wastewater treatment plants in the Keys with their method of treatment, method of effluent disposal, permitted capacity and average flow data.

- Parcel database of land ownership by wastewater study area.

The *Monroe County Sanitary Wastewater Master Plan* identified 246 wastewater treatment plants that provide wastewater treatment in the Keys. An updated file containing 310 permitted wastewater treatment plants, including additional new treatment plants throughout the Keys was obtained from FDEP. Although the list contained the recently permitted wastewater treatment plants, information such as treatment capacities and effluent disposal methods were not provided.

Effluent disposal methods were identified for each of the 246 wastewater treatment plants listed in the Master Plan. Most of these wastewater treatment plants have multiple injection wells per facility. The majority of these wells are shallow wells with depths ranging from 60 to 90 feet. Only the Richard A. Heyman wastewater treatment plant in Key West uses a deep injection well (depth of approximately 3,000 feet). A few of the wastewater treatment plants have reuse land application systems, such as subsurface irrigation and a sprayfield. These disposal systems discharge to the shallow groundwater system.

The disposal method for the on-site systems such as cesspools, septic systems, and substandard septic systems is to discharge to shallow groundwater. The pollutant loads from systems with shallow disposal wells and shallow groundwater discharges will be further dispersed by the Groundwater Component for predicting impacts to the immediate nearshore waters. Discharges to deep injection wells will be further dispersed in the Disposal Well Component to predict impacts to the immediate nearshore waters from these discharges.

The *Monroe County Sanitary Wastewater Master Plan* did not identify the location of point(s) of effluent disposal. However, the Contractor obtained a list from FDEP in Tallahassee for groundwater injection wells in the Keys. Information that was included in the list consisted of permit numbers, owner names, locations (with GIS coverage), and well construction details such as depth of open hole and depth of casing. This information is used in the Groundwater and Disposal Well Components. These Components are discussed further in the respective sections of this report.

3.4.2   Resulting Data

The results of the foregoing investigation and data acquisition/review activities have produced datasets for the Wastewater Component of the Integrated Water Module that will be incorporated into the CCAM database. New data sets were developed to address three areas of interest, which include wastewater planning and characteristics for Monroe County, and the cities of Marathon, and Key West. Each of these elements is discussed in more detail in the following paragraphs.

Monroe County

Based on review of the data in the *Monroe County Sanitary Wastewater Master Plan,* a number of the data limitations were identified, which required the development of supplemental data sets for use in the Wastewater Component. They are listed as follows:

- The inventory of wastewater treatment plants did not include Key West. An updated list of permitted wastewater treatment plants throughout the Keys and including Key West was obtained from FDEP, which for most facilities, did not include detailed information on the number and type of connections, treatment standards, or permitted treatment capacities. Additional data was collected from FDEP, FDOH and individual plant operators to complete the updated list.

- A delineation of wastewater treatment plant service areas was not provided.

- The location of point(s) of effluent disposal was not identified. The Contractor obtained a list of effluent disposal injection wells from FDEP Tallahassee in GIS format. The disposal wells were later associated with the corresponding treatment plant and treatment level.

Although the Master Plan estimates the distribution of permitted systems, ATU's, and unknown systems in Monroe County and within planning units, it did not assign a specific type of on-site treatment units to individual parcels. The Master Plan shows approximately 80 percent of the database parcels labeled as "UNKNOWN SYSTEM." Clearly, that 80 percent of the parcels in Monroe County are not cesspools or illegal systems. The Master Plan states that of the total 23,000 on-site systems, only 30 percent of the 7,200 unknown systems are illegal cesspools. The Contractor used the information provided in the Master Plan and best professional judgment to assign a specific treatment type to each parcel labeled as "UNKNOWN SYSTEM" in the CCAM database. As in the Master Plan, cesspools were assigned to the older buildings within each planning unit. Distribution of the remaining types of on-site systems to individual parcels was controlled according to the numbers provided in the Master Plan while the number of disaggregated EDUs was controlled at the planning unit level.

Marathon

The *Wastewater Facilities Plan for Marathon* (June 1998) was obtained to assist in the determination of wastewater treatment plant service areas in Marathon. However, a delineation of service areas was not included in the plan. There are approximately 68 treatment plants in Marathon. Assumptions had to be made on wastewater treatment plant service areas. Detailed wastewater service information such as number of connections, type of customers, and condominium names were utilized if available in the *Monroe County Sanitary Wastewater Master Plan.*

Key West

The Contractor contacted the City of Key West to obtain a copy of their wastewater master plan. However, no updated wastewater master plan was available. The City has a §201Wastewater Facilities Plan, which is nearly 20 years old. Since the data is outdated, this document was not obtained or reviewed. Mr. David Fernandez at the City of Key West Utilities Department provided the following useful information regarding wastewater service in Key West:

- Nearly all of the septic tanks in Key West have been replaced with a regional wastewater collection and treatment system.

- Wastewater service is provided by a 10.0 mgd wastewater treatment plant meeting secondary treatment standards.

- Current average daily flow is approximately 4.0 mgd. While the flows in Key West have historically been higher, the higher flow rates represented a mixture of wastewater and infiltrated groundwater from older leaking collection systems. These are undergoing repair. The infiltrated groundwater

and stormwater flows elevate the gauged flows at the Key West WWTP, but do not represent an increase in pollutant loads to the WWTP. Consequently, past wastewater records have to be used with caution.

- The wastewater treatment plant has one deep injection well at a depth of 3,000 feet that is used as the exclusive effluent disposal method, having replaced the City's previous ocean outfall. The wastewater effluent that is discharged to the deep disposal well is essentially lost from the groundwater system and never is discharged to marine waters.

- Information provided on population, number of equivalent dwelling units, and estimated gallons per day per equivalent dwelling unit (gpd/EDU).

A review of FKAA water use records for the calendar years 1995-2000 was conducted using population characteristics data from the planning report *Monroe County Population Estimates & Forecasts 1990 to 2015*. An algorithm was developed for estimating current and future water and wastewater generation rates within a specific wasteshed based upon the number of EDUs.

Monthly water usage for the City of Key West, obtained from the FKAA, included information on population and number of total and seasonal housing units. This information was used to assess total gallons of wastewater generated in Key West. However, the data could not be used to determine seasonal wastewater generation since dwelling units cannot account for tourist and commercial usage.

3.4.3 Revised Component Formulation

The revised formulation for the Wastewater Component contains three distinct elements that address wastewater volumes to be treated by specific treatment methods, estimate pollutant loads associated with each treatment method, and aggregate the effluent volume and pollutant loads for each wasteshed by disposal method. Each of these elements is discussed in more detail in the following paragraphs.

Estimation of Wastewater Volumes by Treatment Method

For each scenario, the Wastewater Component will estimate the daily wastewater volumes associated with each specific type of treatment based upon current parcel land use, existing wastewater generation rates, and the current treatment method associated with each parcel. Data requirements include:

- Parcel land use classification,
- Parcel potable water demand estimates adjusted to include tourists and seasonal residents,
- EDU allocation,
- Standardized EDU allocations by specific land-use types for new development,

- GIS mapping of wastesheds within each of the 28 wastewater planning areas, and

- Standardized wastewater generation rates per EDU by wastewater planning area.

Scenario input requirements include:

- User specified treatment system upgrade from on-site treatment systems (septic tanks, ATU, substandard septic tanks, and cesspools) to Best Available Technology (BAT) On-Site Wastewater Nutrient Reduction Systems (OWNRS) or similar systems,

- User specified treatment system upgrade from on-site treatment system (septic tank, ATU, substandard septic tank, and cesspool) to regional wastewater treatment,

- User specified replacement of OWNRS with regional wastewater treatment,

- User specified upgrade from Secondary Treatment to Advanced Wastewater Treatment, and

- These user specified conversion of parcel status to the treatment defined in the Master Plan.

These wastewater parameter inputs represent the Contractor's understanding of potential scenarios as of March 2001. Subsequent CCAM work activities on other delivery orders have further refined the ranges and combination of factors in the current GUI. The scenarios have been modified and are discussed in the DO 11 and DO 12 Reports. Computations of wastewater volumes will be executed at the parcel level and then aggregated GUI at the wasteshed level by specific treatment types. These wasteshed characteristics will be further aggregated to the level of the 28 wastewater planning areas and then summed to produce the estimated total wastewater generated by specific treatment type for the entire Study Area for the given scenario.

Estimation of Pollutant Loads Associated with Each Treatment Method

For each scenario, the pollutant loads will be estimated for the aggregated flows being treated by each on-site wastewater technology and wastewater treatment plant. Data requirements include:

- Standardized pollutant concentrations of treated wastewater effluent for on-site systems,

- Standardized pollutant concentrations of treated wastewater effluent for OWNRS,

- Standardized pollutant concentrations of treated wastewater effluent for secondary treatment, and

- Standardized pollutant concentrations of treated wastewater effluent for advanced Secondary treatment.

Computations of wastewater pollutant loads will be executed at the wasteshed level for each treatment technology, then aggregated to the level of the 28 wastewater planning areas, and then summed to produce the estimated total wastewater pollutant load for the entire Study Area for the given scenario.

Aggregation of Effluent Volumes and Pollutant Loads by Disposal Method

For each scenario, the effluent pollutant loads from each on-site wastewater treatment system and package wastewater treatment plant will be aggregated by respective disposal methods. Data requirements include:

- Standardized pollutant concentrations for the effluent generated by each treatment technology for existing land development,
- Standardized pollutant concentrations for the effluent generated by each treatment technology for new development, and
- Standardized effluent disposal method for each treatment technology.

Scenario input requirement includes:

- User specified treatment method decisions at the parcel level.

Computations of effluent pollutant loads will be executed at the wasteshed level by specific treatment technology and then accumulated by disposal method. These wasteshed volumes and loads will subsequently be aggregated to the level of the 28 wastewater planning areas and then summed to produce the estimated total effluent pollutant load for the entire Study Area for the given scenario.

The original Wastewater Component development proposed the use of permanent and seasonal populations. However, due to the nature of the seasonal community and the existing parcel database by landowner, it was determined that estimates of wastewater generation would be conducted based on EDUs rather than population. Therefore, any previous reference to population data will now be referred to as equivalent dwelling unit. In addition, the original Wastewater Component development included formulation for direct discharge to the initial immediate nearshore waters. However, upon further evaluation, it appears that there are no direct discharges to the immediate nearshore waters. Therefore, these variables were eliminated from the Component formulation.

3.4.4   Enabling Assumptions and Completion of the Database for Component Development

As discussed in Section 3.4.2, due to data limitations several assumptions had to be made to enable completion of the database for use in the Wastewater Component. The methodology used to complete the database for use in the component and the assumptions made are described below.

Completion of the Wastewater Treatment Method in the Database

As discussed previously, the inventory of on-site wastewater systems was incomplete, with approximately 80 percent of the estimated wastewater treatment systems missing from the wastewater database developed in the Master Plan. According to the Master Plan, there are approximately 23,000 private on-site systems, which consist of the following breakdown:

- 15,200 Permitted Septic Systems,
- 7,200 Unknown (Unpermitted) Systems, and
- 640 ATUs.

Of the 7,200 unknown or unpermitted systems, 2,800 are believed to be cesspools, which provide little to no treatment according to the Master Plan. The Master Plan provided an estimation of the distribution of on-site systems per wastewater study area, as shown in Table 20. Although the estimated distribution of on-site systems was provided in the Master Plan, this information was not aggregated in the wastewater database. Only a limited number of the parcels were labeled with "septic tank," "cesspool," "ATU," or "sub-standard system." An even smaller percentage of the parcels contained "FDEP Secondary" in the wastewater treatment method field.

In order to complete the dataset for use in the Wastewater Component, the following assumptions were made based on the information provided:

- The number of treatment system types per wastewater study area presented in the Master Plan was correct;
- Unknown systems consisted of unpermitted septic tanks, cesspools, ATUs, and substandard systems;
- Older buildings such as those constructed before 1970 were more likely to have cesspools as their on-site system; and
- If there was a "septic tank" listed in the field that was built before 1970, this information was assumed correct.

TABLE 20

ALLOCATION OF EXISTING ON-SITE SYSTEMS

No.	Study Area	No. of Developed Lots	No. of Unknown Systems[1]	Adjusted Cesspool Estimate[2]	Estimated Substandard Septic System	No. of ATUs	Remaining Lots (Septic Systems)	Total On-Site Systems[3]
1	Stock Island	1,159	82	27	18	5	423	473
2	Boca Chica	1,240	336	64	43	18	915	1,039
3	Bay Point	234	195	35	23	7	167	233
4	Lower Sugarloaf	460	49	2	1	38	417	458
5	Upper Sugarloaf	247	90	15	10	13	205	243
6	Cudjoe Key	1,399	77	25	17	137	669	848
7	Summerland Key	688	152	15	10	34	628	687
8	Big Torch/Middle Torch Keys	56	12	4	3	0	49	56
9	Ramrod Key	412	60	8	5	110	287	410
10	Little Torch Key	621	162	40	27	18	536	620
11	Big Pine Key	2,755	735	235	157	158	2,198	2,748
12	Bahia Honda Key	9	1	0	0	0	5	5
13	Marathon Primary	3,866	1,618	1,279	853	21	1,702	3,855
14	Marathon Secondary	746	194	24	16	9	684	733
15	Long Key/Layton	517	11	6	4	2	149	161
16	Lower Matecumbe	792	185	40	27	0	722	789
17	Upper Matecumbe	519	213	60	40	11	394	505
18	Windley Key	28	4	2	1	0	19	22
19	Plantation Key	2,135	559	176	117	1	1,832	2,127
20	Tavernier PAED 15	1,135	322	80	53	2	722	858
21	Rock Harbor PAED 16	936	217	60	40	0	829	929
22	PAED 17	1,333	351	77	51	11	1,188	1,327
23	PAED 18	2,103	895	321	214	21	1,545	2,101
24	PAED 19 and 20	1,497	681	160	107	15	1,209	1,491
25	PAED 22[4]		0	0	0	0	0	0
26	PAED 21	82	18	15	10	6	51	82
27	Ocean Reef Club	724	0	0	0	2	256	258
	TOTALS	**25,693**	**7,129**	**2,770**	**1,847**	**640**	**17,801**	**23,058**

Notes:

[1] Approximate number provided by DOH.

[2] According to DOH records, approximately one third of all unknown system that have been inspected were confirmed as cesspools. The number of cesspools in each Study Area was calculated as (No. of unknown system lots) x (0.333) x (lot year factor), to assign more cesspools to Study Areas with older developed lots.

[3] Total on-site systems = (cesspools + substandard septic systems + ATUs + septic systems).

[4] Study Area 25 only has two developed parcels, based on GIS information provided. Thus, not included above.

Source: *Monroe County Sanitary Wastewater Master Plan* (CH2MHILL, 2000).

Using these assumptions, the distribution of on-site systems was entered into the database. The total number of septic systems and cesspools were closely matched to those identified in the Master Plan per Study Area. There were some inconsistencies in the data in the original spreadsheet that was provided. For example, there were instances where the original database had more ATUs listed than those identified in the Master Plan. This information remained unchanged. Only information that was left blank or contained "unknown system" was assigned a treatment method using best professional judgment based on the number of system types indicated in the Master Plan. After a working Wastewater Component is developed, the user can revise the type of wastewater treatment system if site-specific information becomes available.

Estimation of Equivalent Dwelling Units

As discussed previously in Section 3.2, Potable Water Demand Component, wastewater flows were estimated based on water use records from FKAA for each of the 27 Study Areas in the *Monroe County Sanitary Wastewater Master Plan*. According to the Master Plan, 100 percent of the water usage was assumed equivalent to the wastewater generation. Distribution of the water use records to the parcel level was initiated but never completed in the Master Plan due to incomplete RE numbers and data matching problems in the FKAA and the Property Appraiser's databases. Water use and subsequently, wastewater generation was allocated by Study Area.

A review of the potable water consumption data from FKAA, as previously presented in Table 11, suggests that there is a significant variability in monthly consumption in each of the FKAA billing areas. The following table indicates that the maximum:minimum ratio of monthly consumption varies from 35 percent-60 percent with the ratio being 1.43 for the entire Keys (Table 21).

TABLE 21
BILLING AREA RATIOS

FKAA Billing Area	Max Month (MG)	Min Month (MG)	Max:Min Ratio
1	5.0	3.7	1.35
2	1.8	1.3	1.38
3	2.5	1.7	1.47
4	1.6	1.0	1.60
5	3.1	2.1	1.48
Combined	14.0	9.8	1.43

There is no data available on the number and location of parcels that have lawns, the proportion of the lawns that are watered, or the amount of potable water that is used to water lawns. Travel through the Study Area over the last year generally provides the following anecdotal evidence regarding lawns:

- A relatively small percentage of the residential parcels actually have any significant area of maintained turf that would reasonably be classified as an irrigated lawn.

- Most commercial properties, excluding larger hotels and motels, do not have significant area of maintained turf that would reasonably be classified as an irrigated lawn.

Consequently, the enabling assumption that potable water becomes wastewater will be retained in the absence of any documentation of irrigation uses.

An estimation of EDUs on a parcel level was conducted by the Contractor based on assumed density per land use category. These assumed densities were based on typical development planning data for categories such as single- and multi-family residential developments, and

mixed-use commercial properties. However, conservative values on the upper end of the density ranges were used in an attempt to match as closely as possible to the wastewater flows presented in the Master Plan (by wastewater study area). Additionally, where typical planning data was not available, assumptions were made using best professional judgment techniques for land uses such as restaurants and hotels where typical wastewater generation data such as the number of seats or number of hotel rooms was not available. The assumed densities per land use categories that were used to estimate EDUs in the database are indicated in Table 11 previously presented in Section 3.2, Potable Water Demand Component.

The wastewater flow distribution by treatment method for the 27 wastewater study areas as estimated by the Contractor is shown in Table 22. Based on the above-described method to assign EDUs at a parcel level and the gpd/EDU used in the *Monroe County Sanitary Wastewater Master Plan*, the resulting EDUs and corresponding flows are shown in Table 23.

Identifying Wastewater Treatment Plant Facility Identification Numbers, Number of Connections

The inventory of wastewater treatment plants provided in the Master Plan contained useful information such as Facility Name, Facility ID, Permitted Capacity, Current Average Daily Flows, effluent disposal method, and the type and number of connections served such as "300 RV/Trailer sites." This information was used to determine which parcels and the estimated number of parcels served by the respective wastewater treatment plants.

Delineation of wastewater treatment plant service areas was not available in the Master Plan or from FDEP. Service areas were identified by using facility name, treatment capacity, location and type of connections such as "condominiums," if available. In some cases, assumptions had to be made using best judgment practices in order to complete the database.

TABLE 22
ESTIMATED DISTRIBUTION OF WASTEWATER FLOW BY TREATMENT METHODS

No.	Study Area	Total On-Site Flow mgd[1,2]	FDEP WWTP Flow mgd[1,2]	Total Flow mgd[1,2]
1	Stock Island	0.04	0.45	0.49
2	Boca Chica*	0.21	0.17	0.38
3	Bay Point	0.03	0.01	0.04
4	Lower Sugarloaf	0.12	0.02	0.14
5	Upper Sugarloaf	0.05	0.04	0.09
6	Cudjoe Key	0.13	0.06	0.19
7	Summerland Key	0.13	0.29	0.42
8	Big Torch/Middle Torch Key	0.02	0.00	0.02
9	Ramrod Key	0.07	0.00	0.07
10	Little Torch Key	0.11	0.01	0.11
11	Big Pine Key	0.48	0.05	0.53
12	Bahia Honda/Ohio Key	0.00	0.08	0.08
13	Marathon Primary	0.93	0.48	1.41
14	Marathon Secondary	0.21	0.15	0.36
15	Long Key/Layton	0.03	0.08	0.11
16	Lower Matecumbe	0.17	0.01	0.18
17	Upper Matecumbe	0.23	0.19	0.42
18	Windley Key	0.03	0.10	0.14
19	Plantation Key	0.52	0.13	0.65
20	Tavernier, PAED 15	0.18	0.08	0.26
21	Rock Harbor, PAED 16	0.11	0.18	0.29
22	PAED 17	0.39	0.12	0.51
23	PAED 18	0.32	0.09	0.41
24	PAED 19 & 20	0.35	0.10	0.46
25	PAED 22[3]	0.00	0.00	0.00
26	PAED 21	0.03	0.00	0.03
27	Ocean Reef Club	0.06	0.23	0.29
SUBTOTALS		**4.96**	**3.14**	**8.09**
0	Key West	.02	4.24	4.26
TOTAL		**4.97**	**7.38**	**12.35**

Notes: [1] Estimated by URS based on water use records and distribution of on-site systems versus FDEP wastewater treatment plants.
[2] Flows rounded to nearest hundredth.
[3] Study Area 25 has only two parcels with flows, which results in an insignificant quantity.

TABLE 23
ESTIMATED WASTEWATER FLOW RATES AND EDUS
BY WASTEWATER STUDY AREA

No.	Study Area	gpd/EDU[1]	Total Wastewater Flow[2] (mgd)	EDUs[3]
1	Stock Island	168	0.49	2,891
2	Boca Chica	149	0.38	2,555
3	Bay Point	119	0.04	362
4	Lower Sugarloaf	181	0.14	754
5	Upper Sugarloaf	156	0.09	573
6	Cudjoe Key	110	0.19	1,770
7	Summerland Key	149	0.42	2,810
8	Big Torch/Middle Torch Key	200	0.02	102
9	Ramrod Key	146	0.07	526
10	Little Torch Key	135	0.12	853
11	Big Pine Key	132	0.53	4,040
12	Bahia Honda/Ohio Key	160	0.08	490
13	Marathon Primary	160	1.41	8,796
14	Marathon Secondary	172	0.36	2,167
15	Long Key/Layton	116	0.11	978
16	Lower Matecumbe	151	0.18	1,250
17	Upper Matecumbe	167	0.42	2,491
18	Windley Key	150	0.14	926
19	Plantation Key	158	0.65	4,118
20	Tavernier, PAED 15	125	0.26	2,115
21	Rock Harbor, PAED 16	115	0.29	2,528
22	PAED 17	155	0.51	3,302
23	PAED 18	134	0.41	3,080
24	PAED 19 & 20	143	0.46	3,373
25	PAED 22	160	0.00	0
26	PAED 21	160	0.03	205
27	Ocean Reef Club	112	0.29	2,602
SUBTOTAL:		**147[4]**	**8.09**	**55,775**
0	Key West	132	4.26	32,350
TOTAL:		**147[4]**	**12.35**	**88,125**

Notes:

[1] *Monroe County Sanitary Wastewater Master Plan* (CH2MHILL, 2000) with exception to Key West data, which was added by URS.

[2] Calculated based on EDUs estimated by URS and Monroe County WW Master Plan's gpd/EDU.

[3] EDUs estimated by URS.

[4] Average Value.

[5] Flows do not include the small flows from live-aboard boats. Flows from live-aboard boats are estimated in the Boating Discharge Component.

The assumptions that were used are as follows:

- To determine the estimated number of parcels, or more specifically, the number of EDUs served by the wastewater treatment plant, the average daily flow of the wastewater treatment plant in terms of gpd was divided by the wastewater generation value for the respective wastewater planning area in terms of gpd/EDU. The resulting EDUs were then entered into the "Assumed EDU" field (Ass_EDU) in the wastewater database.

- The number of EDUs was assumed based on the estimated water demands, as described in Section 3.2, Potable Water Demand.

- 100 percent of water usage was assumed to be equivalent to wastewater generation.

- If a parcel code was of the connection type identified in the treatment plant list and was located near the wastewater treatment, it was assumed to be served by this wastewater treatment plant.

- If the name of the wastewater treatment plant matched the parcel owner name, then it was assumed that the FDEP wastewater treatment plant served this parcel.

If the wastewater treatment plant serving each parcel could be identified, the facility ID number was entered into the FAC_ID field in the database. The Contractor has requested that FDEP provide the capacity information for the new wastewater treatment plants. This list was not available at the time of this report production, but will be utilized when available to verify the estimated number of EDUs entered in the affected parcels.

Identifying Effluent Disposal Method

The method of effluent disposal for the on-site wastewater treatments systems and the FDEP wastewater treatment plants are required for the assimilation of pollutant loads to the respective Groundwater and Disposal Well Components. The method of effluent disposal was assumed based on the treatment technology, as follows:

- Cesspools, septic tanks, substandard septic tanks were assumed to discharge to shallow groundwater.

- Sprayfields, sub-surface irrigation systems and other land application systems were assumed to discharge to shallow groundwater.

- ATUs and FDEP wastewater treatment plants were assumed to discharge to shallow wells.

- Since only one FDEP wastewater treatment plant discharges to a deep injection well, this facility will be identified separately in the effluent disposal method lookup table.

Identifying Location of Points of Effluent Disposal

To identify the locations of the effluent disposal point source loads, the following assumptions were made:

- The effluent disposal point source loads for the FDEP wastewater treatment plants were assumed to be located at the wastewater treatment plant sites.

- The effluent disposal point source loads for the on-site treatment systems were assumed to located with the assigned parcel in each wasteshed.

Identifying Pollutant Characteristics

The on-site treatment systems and the FDEP wastewater treatment plants have varying pollutant characteristics and even among similar technologies the effluent characteristics may vary. However, for use in the Wastewater Component, the following assumptions were made:

- All wastewater treatment plants providing secondary treatment had the maximum contaminant limitations of 20 mg/l BOD, 20 mg/l TSS, 20 mg/l TN and 5 mg/l TP.

- Little to no treatment was assumed for cesspools, based on available reference documents.

The pollutant characteristics for the various treatment methods as provided by FDEP, are summarized in Table 24. This wastewater quality information will be used in the appropriate disposal component for assessing impacts to the immediate nearshore waters.

TABLE 24
SUMMARY OF WASTEWATER CHARACTERISTICS

Treatment Method	Carbonaceous BOD (mg/l)	TSS (mg/l)	TN (mg/l)	TP (mg/l)
None (Raw Sewage) and Cesspits	200	200	35	6
Substandard (Unpermitted) On-site Treatment and Disposal System	140	85	32	6
Approved On-site Treatment and Disposal System	10	10	25	5
Secondary Treatment	20	20	25	5
Best Available technology, Including On-Site Treatment and Disposal Systems with Nutrient Removal	10	10	10	1
Advanced Wastewater Treatment	5	5	3	1

Source: Florida Department of Environmental Protection.

3.4.5   Current Computational Algorithm

The Wastewater Component will estimate the daily aggregate wastewater flows for each parcel in the wastewater study areas using the estimated EDUs per parcel and multiplying by the wastewater generation (gpd/EDU) for the respective wastewater study area. Wastewater

generation at the parcel level was attributed to discrete sources (cesspools, septic tanks, ATUs, sub-standard septic tanks, or wastewater treatment plants). The corresponding standard pollutant concentrations per treatment method multiplied by the wastewater volumes for each parcel determines pollutant loads. Discharge volumes and pollutant loads from individual sources are accumulated based upon their method of effluent disposal (land application, shallow well or deep well) using GIS techniques. The aggregated flows and pollutant loads are passed to the Groundwater and Disposal Well Components by specific catchments.

The following definitions are provided for the input variables, output variables and management variables used in the computational algorithms for Wastewater Component.

Input Variables

- CATCH = Catchment Number (*n*) as defined from the Integrated Stormwater-Wastewater-Circulation Assessment Block GIS overlay developed for the modeled islands of the Florida Keys.

- EDUCESS [*d, n*] = Equivalent dwelling units assigned to Catchment Number (*n*) for a specific day date (*d*) during the simulation period, that use cesspools for wastewater treatment.

- EDUSEPTIC [*d, n*] = Equivalent dwelling units assigned to Catchment Number (*n*) for a specific day date (*d*) during the simulation period, that use septic tanks for wastewater treatment.

- EDUATU [d, n] = Equivalent dwelling units assigned to Catchment Number (*n*) for a specific day date (*d*) during the simulation period, that use ATUs for wastewater treatment.

- EDUSBSTDSEP [*d, n*] = Equivalent dwelling units assigned to Catchment Number (*n*) for a specific day date (*d*) during the simulation period, that have substandard septic tanks for wastewater treatment.

- EDUPKGWWTP [*d, n*] = Equivalent dwelling units assigned to Catchment Number (*n*) for a specific day date (*d*) during the simulation period, that are served by package wastewater treatment system meeting secondary treatment standards.

- EDUOWNRS [*d, n*] = Equivalent dwelling units assigned to Catchment Number (*n*) for a specific day date (*d*) during the simulation period, that are served by on-site wastewater nutrient reduction systems.

- EDUAWTWWTP [*d, n*] = Equivalent dwelling units assigned to Catchment Number (*n*) for a specific day date (*d*) during the simulation period, that are served by a wastewater treatment system meeting advanced wastewater treatment (AWT) standards.

- PSDCESSVOL2GW [*d, n*] = Point Source Discharge Volume data array for those point sources from cesspools that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily

volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDSEPTICVOL2GW [*d, n, x*] = Point Source Discharge Volume data array for those point sources from septic tanks that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDATUVOL2GW [*d, n, x*] = Point Source Discharge Volume data array for those point sources from ATUs that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDSUBSTDSEPVOL2GW [*d, n, x*] = Point Source Discharge Volume data array for those point sources from substandard septic tanks that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDPKGWWTPVOL2GW [*d, n, x*] = Point Source Discharge Volume data array for those point sources from package wastewater treatment plants that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDOWNRSVOL2GW [*d, n, x*] = Point Source Discharge Volume data array for those point sources from OWNRS that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDAWTWWTPVOL2GW [*d, n, x*] = Point Source Discharge Volume data array for those point sources from AWT WWTPs that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDPKGWWTPVOL2DW [*d, n, x*] = Point Source Discharge Volume data array for those point sources from package WWTPs that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily volume (measured in decimal mgd) for a specific day date (*d*) during the simulation period.

- PSDCESSLOAD2GW [*d, n, y*] = Point Source Discharge Load data array for those point sources from cesspools that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- PSDSEPTICLOAD2GW [*d, n, y*] = Point Source Discharge Load data array for those point sources from septic tank s permitted by FDEP that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- PSDATULOAD2GW [*d, n, y*] = Point Source Discharge Load data array for those point sources from ATU's permitted by FDEP that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- PSDOWNRSLOAD2GW [*d, n, y*] = Point Source Discharge Load data array for those point sources from OWNRS's permitted by FDEP that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- PSDSUBSTDSEPLOAD2GW [*d, n, y*] = Point Source Discharge Load data array for those point sources from substandard septic tanks permitted by FDEP that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- PSDPKGWWTPLOAD2GW [*d, n, y*] = Point Source Discharge Load data array for those point sources from package wastewater treatment plants permitted by FDEP that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- PSDAWTWWTPLOAD2GW [*d, n, y*] = Point Source Discharge Load data array for those point sources with advanced wastewater treatment permitted by FDEP that discharge to the groundwater system of Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- PSDPKWWTPLOAD2 DW [*d, n, y*] = Point Source Discharge Load data array for those point sources from package wastewater treatment plants permitted by FDEP that are discharged by deep well injection to a confined zone underlying Catchment Number (*n*), provided in the form of the aggregated daily load (measured in decimal pounds) of pollutant (*y*), for a specific day date (*d*) during the simulation period.

- VLEDU [*n, x*] = the volume of wastewater per EDU (measured in gallons/EDU/day) generated in a Catchment Number (*n*), which varies per Study Area (*x*).

- POLLCON [*n, y*] = the daily pollutant concentration (measured in mg/l) of a specific modeled pollutant (*y*).

Output Variables

- WWLOAD2GW [*n, d, y*] = the total daily pollutant load (measured in decimal pounds) of a specific modeled pollutant (*y*), discharged to the groundwater system of a given catchment (*n*), for a specific day date (*d*) during the simulation period.

- WWVOL2GW [*n, d*] = the total daily volume (measured in decimal mgd) of wastewater discharged to the groundwater system of a given catchment (*n*), for a specific day date (*d*) during the simulation period.

- WWLOAD2DW [n, d, y] = the total daily pollutant load (measured in decimal pounds) of a specific modeled pollutant (*y*), discharged to the deep well disposal systems, in a given catchment (*n*), for a specific day date (*d*) during the simulation period.

- WWVOL2DW [*n, d*] = the total daily volume (measured in decimal mgd) of wastewater discharged to deep well disposal systems, in a given catchment (*n*), for a specific day date (*d*) during the simulation period.

Not discussed above are the input variables from the Boating Component. A separate component will determine the pollutant loadings {BDLOAD2POF [*n, d, y*]}and volume of wastewater {BDVOL2POF [*n, d*]} generated from boat wastes.

Computational algorithms using the above referenced input and output variables will be utilized in the Wastewater Component based on the relationships between wastewater generation, treatment method, pollutant characteristics and effluent disposal mechanisms.

Algorithms

Wastewater Volumes (gpd) by Treatment Method

- EDUCESS [*d, n*] x VLEDU [*n, x*] = PSDCESSVOL2GW [*d, n, x*]

- EDUSEPTIC [*d, n*] x VLEDU [*n, x*] = PSDSEPTICVOL2GW [*d, n, x*]

- EDUATU [*d, n*] x VLEDU [*n, x*] = PSDATUVOL2GW [*d, n, x*]

- EDUSUBSTDSEPTIC [*d, n*] x VLEDU [*n, x*] = PSDSBSTDSEPVOL2GW [*d, n, x*]

- EDUPKGWWTP [*d, n*] x VLEDU [*n, x*] = PSDPKGWWTPVOL2GW [*d, n, x*]

- EDUOWNRS [*d, n*] x VLEDU [*n, x*] = PSDOWNRSVOL2GW [*d, n, x*]

- EDUAWTWWTP [*d, n*] x VLEDU [*n, x*] = PSDAWTWWTPVOL2GW [*d, n, x*]

- EDUPKGWWTP [*d, n*] x VLEDU [*n, x*] = PSDPKGWWTPVOL2DW [*d, n, x*]

Pollutant Loading (lb/day) per Treatment Method

- PSDCESSVOL2GW [*d, n, x*] x POLLCON [*y*] x 8.34lb/mgd = PSDCESSLOAD2GW [*d, n, y*]

- PSDSEPTICVOL2GW [*d, n, x*] x POLLCON [*y*] x 8.34 lb/mgd = PSDSEPTICLOAD2GW [*d, n, y*]

- PSDATUVOL2GW [*d, n, x*] x POLLCON [*y*] x 8.34 lb/mgd = PSDATULOAD2GW [*d, n, y*]

- PSDSBSTDSEPVOL2GW [*d, n, x*] x POLLCON [*y*] x 8.34lb/mgd = PSDSBSTDSEPLOAD2GW [*d, n, y*]

- PSDPKGWWTPVOL2GW [*d, n, x*] x POLLCON [*y*] x 8.34 lb/mgd = PSDPKGWWTPLOAD2GW [*d, n, y*]

- PSDOWNRSVOL2GW [*d, n, x*] x POLLCON [*y*] x 8.34 lb/mgd = PSDOWNRSLOAD2GW[*d, n, y*]

- PSDAWTWWTPVOL2GW [*d, n, x*] x POLLCON [*y*] x 8.34 lb/mgd = PSDAWTWWTPLOAD2GW [*d, n,* y]

- PSDPKGWWTPVOL2DW [*d, n, x*] x POLLCON [*y*] x 8.34 lb/mgd = PSDPKGWWTPLOAD2DW [*d, n, y*]

Aggregation of Effluent Volumes and Pollutant Loads by Disposal Method

- TWWVOL2GW [*n, d*] = E PSDVOL2GW (all)

- TWWVOL2DW [*n, d*] = E PSDVOL2DW (all)

- TWWLOAD2GW [*n, d, y*] = E PSDLOAD2GW (all)

- TWWLOAD2DW [*n, d, y*] = E PSDLOAD2DW (all)

3.4.6 Definition of Datasets

Dataset requirements for the Wastewater Component include the following temporally and spatially variable data:

- GIS coverage for parcel locations for the Study Areas.

- GIS coverage for wastewater treatment facilities including their treatment methods and points of effluent disposal.

- GIS coverage for catchment basins.

Other datasets to be used in the Wastewater Component development include:

- Wastewater generation in terms of gpd/EDU for each island.

- Pollutant concentrations based on treatment method.

- Component for further analysis.

- Estimated capital construction costs for OWNRS.

- Cost curve for capital costs to upgrade from Advanced Secondary Treatment to Advanced Wastewater Treatment.
- Cost curve for capital costs for new AWT plant and corresponding collection system construction.

The above referenced datasets were developed in Excel as lookup tables, which will be converted to ArcInfo files for use in the Component program.

3.4.7 Integration Considerations

There is one integration consideration that may impact the results of the Wastewater Component. As discussed previously in this report, and described in substantially greater detail in the DO 10 and DO 11 reports, the GIS coverages received for this project have mapping errors where there is an offset of land coverages. This will have to be taken into account when assessing the impacts to the immediate nearshore waters developed by the CCAM.

3.5 Groundwater Component

The groundwater systems underlying the islands in the Florida Keys play a critical role in determining the pollutant concentrations in the immediate nearshore waters as they convey infiltrated stormwaters and on-site wastewater treatment system effluents to the nearshore waters. The Study Area has been divided into approximately 700 wastesheds – the watersheds defined in the Stormwater Component – that are used to define which portions of the land mass of the Keys discharge their groundwaters to which shorelines.

The Groundwater Component is responsible for 1) accumulating and quantifying, at the wasteshed level, the input volumes and pollutant loads generated by infiltrated stormwaters and on-site wastewater treatment system effluents, 2) providing supplemental treatment, and 3) discharging the accumulated volumes and net pollutant loads to the appropriate immediate nearshore water elements for use by the Marine Module.

3.5.1 Ancillary Investigation Activities

Investigation activities included conducting literature reviews from various agencies, books, and journals. Agencies such as the Florida Geological Survey (FGS), the Miami Geological Society, the SFWMD, and the USGS were contacted and available information regarding the Florida Keys was requested. Described below and arranged by source are the results of the ancillary investigation.

Florida Geological Survey

Data and research on Florida's aquifer systems and geologic framework has been conducted since 1907 by the FGS, a bureau within the Division of Resource Assessment and Management in the FDEP. The FGS has not conducted extensive research in the Florida Keys. Data specific to the Florida Keys that the FGS has produced includes geologic maps, lithologic borings, and reports regarding the geology of the state parks in the Florida Keys.

The Monroe County geologic map and the State of Florida stratigraphy map were downloaded from the FGS website. The geologic map is available in AutoCAD.dxf format, while the stratigraphic map is available in an Environmental Systems Research Institute, Inc. (ESRI) shapefile that can be viewed in ESRI's Arc/Info, ArcView, and ArcExplorer software. Both maps contained the same information with regards to the geology of the Florida Keys. Essentially, the Upper Keys, from Key Largo to Bahia Honda are composed of the Key Largo Limestone, while the Lower Keys from Big Pine Key to Key West are composed of the Miami Limestone. The Miami Limestone overlies the Key Largo Limestone in the Lower Keys, and the surface contact between the two units occurs at the southern tip of Big Pine Key. The maps illustrate that the very southern lobe of Big Pine Key is actually the Key Largo Limestone while the remaining portion of the island is composed of the Miami Limestone.

The only report that the FGS published that is specific to either Monroe County or the Florida Keys is Leaflet No. 14, *Geology of the State Parks in the Florida Keys*, by Ed Lane. This report describes the geology of the five State Parks located in the Florida Keys.

The Florida Keys are situated along an arc from Miami to Key West, a distance of approximately 135 miles. The islands can be divided into the Upper and Lower Keys, based on differences between the two types of limestone, and the orientation of the islands, which is a result of the depositional environment of the limestone. The Upper Keys are composed of the Key Largo Limestone and are oriented in a linear northeast-southwest direction, while the Lower Keys are composed of the Miami Limestone and are oriented in a northwest-southeast direction.

The Florida Keys began to form nearly three million years ago when a shallow sea covered south Florida. Due to responses to the melting and freezing of the polar ice caps, called the Pleistocene Ice Ages, world sea levels underwent many fluctuations of several hundred feet above and below sea level for the next 2.8 million years. Colonies of coral became established in the shallow sea, growing upward when sea levels rose, and retreating to lower depths when the sea level dropped. During times of rising sea levels, the dead reefs provided good substrate for new coral growth, and during these successive phases of growth, the Key Largo Limestone accumulated up to 200-feet thick in places. During the reef growth phase, carbonate sand banks periodically accumulated behind the reefs. After the last sea level drop, a lime-sand bank covering the southwestern end of the coral reefs exposed the ooid bank that formed the Lower Keys.

The Key Largo Limestone is a white to tan limestone that is primarily the skeletal remains of corals, with marine debris and lime-sand. In the Lower Keys, the limestone is overlain by the Miami Limestone. The Miami Limestone is white to light tan, composed of tiny ooliths, lime-sand, and shells. Ooliths are made of concentric layers of calcium carbonate deposited around a nucleus of sand or shell. The Key Largo Limestone thickness can vary from about 75 feet to over 200 feet, while the Miami Limestone thickness varies from a few feet to 35 feet.

The Keys receive the lowest annual amounts of rainfall in Florida, and since the limestone composing the Keys are so permeable and surrounded by saltwater, there are no reliable natural sources of freshwater in the Keys.

FGS' lithologic database contains only ten borings for Monroe County. The borings have a detailed description of the lithology and the depths of the borings range from less than 100 feet to greater than 12,000 feet. No significant clay layer was encountered or described in the core boring descriptions.

U.S. Geological Survey

The USGS has intensively studied the geology of the Florida Keys by conducting research for more than 20 years or more. Because of the low annual rainfall and the high hydraulic conductivity of the Florida Keys' limestone units, there is not much available freshwater. Therefore, not many studies were conducted with regard to water supply. The majority of the work has focused on the recent decline in health of the reefs' that are located seaward of the Florida Keys and the effects of the injection wells that dispose of wastewater into the underlying limestone. These data will be presented in Section 3.6.

E.A. Shinn of the USGS Marine and Coastal Geology Program (St. Petersburg, Florida) was contacted for further information regarding the geologic interpretations he has amassed from all of his projects conducted in the Florida Keys, in particular, the findings he reported in his USGS Open-File Report 94-276, *Fate and Pathways of Injection-Well Effluent in the Florida Keys*. The key hydrogeologic findings in the report were:

- The Holocene mud sediments that cover the bottom of Florida Bay are the most significant confining bed in the offshore Florida Keys reef tract.

- Onshore and nearshore, where Holocene deposits are absent or thin, diagenetic processes, along with boring and infilling have caused the very top of the limestone (just below land surface) to become relatively impermeable.

- Onshore and nearshore, an unconformity between 25 and 35 feet deep serves as a leaky confining bed.

- The Pleistocene limestone is extremely porous and permeable.

However, based on a personnel communication with E.A. Shinn, he states that subsequent borings do not indicate the widespread occurrence of an unconformity that acting as a leaky confining bed. The occurrence of any onshore clay or low permeability deposits that behaves as a confining unit is generally site specific and does not create confined conditions regionally.

There are two recent USGS publications that describe the water resources at Key West and Big Pine Key. The first report, Open File Report 80-447, *Freshwater Resources of Big Pine Key, Florida*, described the freshwater lens occupying Big Pine Key. The second report, Water-Resources Investigation Report 90-4115, *Water-Resources Potential of the Freshwater Lens at Key West, Florida*, described the potential for future development of the freshwater lens at Key West, with regards to quantity and quality. In addition, there are proceedings from the USGS South Florida Ecosystems conference that presents the findings of the multi- and inter-disciplinary studies that have been conducted as part of the USGS's Placed-Based Studies Program.

C.E. Hanson's Open-File Report 80-447, *Freshwater Resources of Big Pine Key, Florida*, investigated the freshwater lens located in Big Pine Key's underlying limestone. Data collected from over 20 newly installed observation wells were examined to determine the extent of the lens and to characterize the fluctuation of the lens with respect to seasons. Water is withdrawn from approximately 150 irrigation wells on the island. Conclusions drawn from the study include the following:

- The Miami Limestone is the primary freshwater bearing zone.

- The extent, depth and configuration of the freshwater lens are influenced by rainfall, discharge, tides, proximity to saltwater bodies, and hydraulic conductivity of the limestone.

- During most of the year, two separate freshwater lenses exist, one in the northern portion of the island and one on the southern portion of the island.

- The maximum depth of the freshwater lens was 5 feet in September.

- In March, the chloride concentration in all of the sampled zones was greater than 250 mg/l (drinking water standard).

D.J. McKenzie's Water Resources Investigation Report 90-4115, *Water Resources Potential of the Freshwater Lens at Key West, Florida*, investigated the local freshwater lens located in the center of Key West. Data from newly installed observation wells and previously installed wells were examined to determine the extent of the lens and to characterize the water quality. Surface geophysical surveys were also conducted in conjunction with water quality analysis to help define the configuration of the lens and the transition zone. An unknown amount of private wells tap the groundwater lens for potable and nonpotable uses. Conclusions drawn from the study include the following:

- There is a substantial amount of freshwater only in the western half of the island.

- The freshwater lens average thickness is approximately five feet, in the center of the Old Town area.

- Underlying the freshwater lens is a transition zone that increases in salinity vertically until the saltwater interface is reached at a depth of approximately 40 feet bls.

- Because the freshwater lens is very thin (one to five feet thick), any heavy pumping might quickly deplete the freshwater lens and cause saltwater intrusion.

Two Open-File Reports, 97-385, *USGS Program on the South Florida Ecosystem – Proceedings of the Technical Symposium in Ft. Lauderdale, Florida, August 26-27, 1997,* and 99-181, *USGS Program on the South Florida Ecosystem - Proceedings of South Florida Restoration Science Forum, May 17-19, 1999, Boca Raton* were obtained. However, the reports primarily contained

abstracts of the findings to date, and did not provide comprehensive descriptions of the results of the project to date.

The first report, Open-File Report 97-385 had two abstracts with respect to the Florida Keys: *Origins, Residence Times, and Nitrogen Chemistry of Marine Ground Waters Beneath the Florida Keys and Nearby Offshore Areas* (J.K. Bohlke, et al.) and *Geology and Hydrology of the Florida Keys: Ground Water Flow and Seepage* (E.A. Shinn, et al.). Significant findings from the two abstracts were:

- The salinity and isotopic results did not support the long-distance transport (more than a few hundred meters) of bay water to the offshore reef tracts.

- It was suggested that the ammonium found offshore was from anaerobic degradation of nitrogen-bearing organic matter in sediments.

- Measurements of pressure heads indicate that tidal pumping combined with higher average sea level in Florida Bay is the major cause of groundwater movement and dispersal to the Atlantic side of the Keys.

- Nutrient levels of saline groundwater in the Keys is greater than that of surface waters.

The second report, Open-File Report 99-181, presented two abstracts dealing with the Florida Keys: *Origins, Residence Times, and Nutrient Sources of Marine Ground Water Beneath the Florida Keys and Nearby Offshore Areas* (J.K. Bohlke et al.), and *Hydrogeology of a Dynamic Marine System in a Carbonate Environment, Key Largo Limestone Formation, Florida Keys* (C.D. Reich, et al.). Both of these abstracts were fundamentally the same as presented in the earlier Open-File Report (97-385), and no new significant findings were reported.

South Florida Water Management District

SFWMD provides flood control and water supply to 16 counties in south Florida, including the Florida Keys. However, since there are no major water supply sources in the Florida Keys (nearly all of the freshwater is piped in from the mainland), the SFWMD has not conducted much research in the Florida Keys. A review of the SFWMD listing of technical publications dating back to 1958 did not reveal any published investigations of the Florida Keys. The SFWMD was contacted to determine how much data they have collected in the Florida Keys. According to Ann-Marie Superchi and Emily Hopkins, respectively, the SFWMD has paper files of well construction permits, and the SFWMD had just conducted a salinity monitoring well installation program at Big Pine Key.

The SFWMD maintains the well construction permits for all of the wells that are constructed in the Keys, primarily observation/monitoring wells and injection wells. However, these permits are not in electronic format, only paper copies of the permits exist. Generally, the well construction permits do not contain information other than the location of the well, the total depth and casing depth, and a brief description of the stratigraphy. Since most of the permits were completed by the well driller, not by a geologist, most of the stratigraphic descriptions are

very basic without much detail. Available well construction permits for the Florida Keys were reviewed. For over 95 percent of the permits, limestone was the only lithologic description noted on the permits. Therefore, it was assumed, based on the well construction permit data, that there was no widespread occurrence of a confining layer present in the Florida Keys.

In addition, the SFWMD just recently completed the construction of salinity monitoring wells in Big Pine Key and descriptions of the core borings were obtained for seven monitoring wells. The seven wells were installed in the north central portion of the island, with an average depth of 35 feet. The core boring descriptions of the wells detailed the lithology of the borings to approximately 35 feet below land surface (bls). There were seven core boring descriptions and five of the boring descriptions listed the contact between the Miami Limestone and the Key Largo Limestone at approximately 30 feet bls. One boring listed the contact at approximately 20 feet bls, while another boring did not encounter the Key Largo Limestone at any depth. The depth to the contact correlates with other studies. Data or knowledge of any other studies conducted in the Florida Keys by the SFWMD was not readily known.

Literature Review

In addition to the data and publications obtained from the various organizations referenced above, a literature review was conducted to obtain articles that have appeared in journals or publications regarding the geology or hydrogeology of the Florida Keys. Summaries of the publications are presented below.

J.E. Hoffmeister and H.G. Multer, *Geology and Origin of the Florida Keys*, 1968, published one of the first papers regarding the geologic aspects of the Florida Keys. The paper provided interpretation of the Pleistocene Epoch geology and the origin of the Florida Keys. The findings of the paper are summarized below:

- Borings have revealed that the extent of the Key Largo Limestone extends as far north as Miami Beach, as far southwest as the Dry Tortugas, 70 miles beyond Key West, and seaward to the Florida Straits.

- The thickness of the Key Largo Limestone can vary from 70 feet to greater than 200 feet.

- The Miami Limestone covers all of the Lower Keys with increasing thickness to the north.

- The shape and the northwest-southeast orientation of the Lower Keys was created by ancient tidal current.

Another paper written by E.A. Shin, *The Geology of the Florida Keys*, 1988, presents a concise overview of how the effects of rising and falling sea levels, in conjunction with topography led to the present growth of reef tracts seaward of the Florida Keys. Summarized below are the key findings of the paper:

- As sea levels began to drop approximately 100,000 years ago, soils formed and calcium carbonate leached by rain percolated into the sediment and formed a brown laminated crust called calcrete.

- Reefs off the coast of Key Largo and from Big Pine Key to Key West are more productive, since the islands formed a barrier that prevented the colder water from Florida Bay and the Gulf of Mexico from reaching and destroying the corals.

- Coral and lime sands that are affected by mechanical and biological abrasion produce lime mud and settle in deep, calm areas, such as Hawk Channel.

R.B. Halley, et al., *Geology and Hydrogeology of the Florida Keys*, 1997, provides an excellent description of the Pleistocene geology of the Florida Keys, with historical references of previous studies, and the current hydrogeology of the Florida Keys. Noteworthy facts are listed below:

- Topographically, the Florida Keys are low and flat, with the highest elevation being only 18 feet.

- The Key Largo Limestone is a complex of shallow-water shelf-margin reefs and associated deposits along a topographic break.

- Regional subaerial discontinuity surfaces within the Quaternary rocks of South Florida were divided into five units, numbered Q1 (oldest) to Q5 (youngest). The Q4 and Q5 units include both the Key Largo and Miami Limestones, and the Q1 to Q3 units include only the Key Largo Limestone.

- The contact between the Miami and Key Largo Limestones corresponds to the contact between the Q5 and older Q units.

- Diagenetic alteration (e.g., dissolution, precipitation, secondary porosity) of the Pleistocene limestones resulted in a rock with high porosity and permeability.

- High permeabilities of the Key Largo Limestone do not allow any significant freshwater lens to occur in the Upper Keys.

- The lower permeable Miami Limestone of the Lower Keys allows small and slightly brackish lenses to occur in the larger islands of the Lower Keys.

- The water resources of the Florida Keys cannot support the population.

A.F. Randazzo and R.B. Halley, *Geology of the Florida Keys*, 1997, summarize the development of the Key Largo and Miami Limestones, as well as the evolution of the Florida Keys and the current reefs. The paper summarized the key findings of pervious publications and all of the important facts contained in the paper have been summarized within this section.

H.L. Vacher, *Dupuit-Ghyben-Herzberg Analysis of Strip-Island Lenses*, 1988, documents analysis for determining the position of the water table and saltwater interface for small, very permeable, and/or lightly recharged islands. Important facts are listed below:

- Combining the continuity equation with the Dupuit assumption of horizontal flow and Darcy's Law with the Ghyben-Herzberg Principle, with respect to island geometry, distribution of hydraulic conductivity, and distribution of recharge allows for the development of analytical equations that describe the steady-state position of the water table and the saltwater interface.

- Accounting for an outflow face or seepage face that extends beyond the shoreline into the ocean can explain for the departure of the Ghyben-Herzberg ratio (1:40) along a narrow strip next to the shoreline.

- Where a high permeable unit underlies a surficial aquifer and the lens extends to the lower unit, the lens is effectively truncated at the top of the lower, higher permeable unit.

H.R. Wanless and M.G. Tagett, *Origin, Growth and Evolution of Carbonate Mudbanks in Florida Bay*, 1989, described the carbonate mud banks in Florida Bay. The mud banks in Florida Bay are a rare modern analogy to ancient muddy carbonate deposits. Findings of the study include:

- Inundated and dissected coastal deposits served as the origin of the present complex of Florida Bay islands, mudbanks, bank spits and bays.

- Seagrasses have had only a minor to moderate role on the growth and evolution of Florida Bay's Mudbanks.

B.E. Lapointe, et al., *Nutrient Couplings Between On-Site Sewage Disposal Systems, Groundwaters, and Nearshore Surface Waters of the Florida Keys*, 1990, conducted direct measurements of subsurface groundwater flow rates in the Miami and Key Largo Limestones. Results of their findings are presented below:

- Average Miami Limestone groundwater flow rate was 0.4 feet/day.

- Average Key Largo Limestone groundwater flow rate was 3.75 feet/day.

- Mean groundwater concentrations of nitrogen and phosphate decreased from winter to summer.

- Groundwater by septic tanks was enriched with nitrogen as compared to phosphate.

- Mean surface water concentrations of nitrogen and phosphate increased from winter to summer.

- Phosphate is removed by interaction with limestone strata.

- Slower groundwater flow rates for the Miami Limestone will enhance the removal capacity for phosphate as compared to the Key Largo Limestone.

- Assuming an average distance of 400 feet from a septic system to the nearest surface water, and an average groundwater flow rate of 2 feet/day, it would take 6 months for the "winter" septic leachate to discharge to the surface waters.

K.S. Dillon, et al., *Bimodal Transport of a Waste Water Plume Injected into Saline Ground Water of the Florida Keys*, 2000, presents results of field studies with regards to groundwater flow rates and hydraulic gradients at Long Key of the Upper Keys. The results are derived from experiments conducted in an injection well 60 to 90 feet deep within the Key Largo Limestone. Measured hydraulic gradients and groundwater flow rates are summarized below:

- Hydraulic gradient ranged from 0.003 to 0.005 foot/day.
- Horizontal groundwater flow rate in the Key Largo Limestone can be as high as 135 feet/day in conduits.
- Primary porosity horizontal groundwater flow rates are less, with an estimated rate of 0.8 feet/day.
- Florida Bay's water level was consistently higher than the Atlantic's water level, thus producing a groundwater flow direction from Florida Bay to the Atlantic.

K.S. Dillon, et al., *The Use of Sulfur Hexafluoride as a Tracer of Septic Tank Effluent in the Florida Keys*, 1999, calculated groundwater flow rates at two sites, one in the Lower Keys (Big Pine Key), and one in the Upper Keys (Key Largo Limestone). Results of their groundwater flow rates study is presented below.

- Groundwater transport rates for the Miami Limestone ranged from 8.7 feet/ day to 147 feet/day.
- Groundwater transport rates for the Key Largo Limestone ranged from 15 feet/day to 291 feet/day.
- Tracer tests results at Key Largo showed that the tracer showed up in the Atlantic Ocean (1,300 feet away) and Florida Bay (85 feet away) in less than 2 days.

D.R. Corbett, et al., *Fate of Wastewater-Borne Nutrients Under Low Discharge Conditions in the Subsurface of the Florida Keys, USA*, 2000, investigated the fate and transport of phosphate and nitrogen from a disposal well located in Long Key. The key facts are presented below:

- As much as 95 percent of the phosphate was removed from the injected subsurface fluids within 15 feet of the injection well after two days.
- As much as 65 percent of nitrate was removed from the injected subsurface fluids within 15 feet of the injection well after three days.

Lapointe and Clark (1992) characterized watershed nutrients inputs, transformations, and effects along a land-sea gradient of four different ecosystems that occur with increasing distance from land. The study findings correlate with observations of increasing algal blooms, seagrass epiphytization and die-off, and loss of coral cover on patch and bank reef ecosystems, suggesting that nearshore waters of the Florida Keys have entered a stage of critical eutrophication.

- In nearshore canal and seagrass meadows human activities on land enrich groundwaters with ammonium and SRP, contributing to elevated concentrations of these nutrients.

- The N:P ratios of sewage-enriched groundwaters are greater than 100:1 in the Keys due to selective adsorption of SRP onto calcium carbonate surfaces.

- SRP and ammonium concentrations decreased to low concentrations within approximately 1 km and 3 km from land, respectively.

- With increasing distance from land the kinetics of dissolved nutrient cycling by marine microbes and plants is very rapid and dissolved organic pools, which are important to biological cycling come to dominate the total nutrient pools.

- Water clarity in the Keys is regulated by short-term meteorological events that increase turbidity and particulate nutrients, primarily in winter, and by increased nutrient loading during the rainy season that increases phytoplankton standing crops.

Paul et al., *Viral Tracer Studies Indicate Contamination of Marine Waters by Sewage Disposal Practices in Key Largo, Florida,* 1995, performed viral tracer studies indicating contamination of marine waters by sewage disposal practices.

- On-site disposal practices employed at the time of the study can lead to contamination of the subsurface and surface marine waters in the Keys.

- The rapid movement of a viral tracer was demonstrated from a seeded septic tank out into the surrounding environment within 11 hours.

- The estimated rates of migration of viral traces through the Key Largo Limestone ranged from 1,905 feet/day to 45 feet/day, over 500-fold greater than flow rates measured previously by subsurface flow meters in similar environments.

Paul et al., *Evidence for Groundwater Surface Marine Water Contamination by Waste Disposal Wells in the Florida Keys,* 1997, investigated the fate and transport of wastewater by utilizing bacteriophages as tracers in a 12.2-m deep simulated injection well in Key Largo and an active 27.4-m deep Class V disposal well in the Middle Keys.

- Rates of migration of viral tracers were greater in Key Largo than in the Middle Keys.

- Viral tracers appeared after short periods of time in groundwater (8 h after injection) and surface marine waters (10 h and 53 h for Key Largo and the Middle Keys, respectively).

- Estimated rates of tracer movement through the Key Largo Limestone ranged from 2,755 feet/day to 9 feet/day.

University of South Florida

Professor H.L. Vacher of the Geology Department at the University of South Florida (USF) specializes in the study of carbonate islands. One of the books that he edited, *Geology and Hydrogeology of Carbonate Islands*, and a journal article he wrote, *Dupuit-Ghyben-Herzberg Analysis of Strip-Island Lenses*, 1988, are being used in this study. He has also been on some graduate thesis committees that dealt with the Florida Keys. Of particular interest are two graduate students' theses on the hydrogeology of Big Pine Key.

C.M. Beaudoin, in *Effects of Dredge and Fill Canals on Fresh-Water Resources of a Small Oceanic Island, Big Pine Key, Florida*, 1990, thesis focused on the effects of canals on the freshwater resources of small islands. Her study was conducted at Big Pine Key. Findings from her thesis are summarized below:

- The depth to the interface on islands consisting of two different horizontal layer materials is largely controlled by the depth to the lithologic contact and the ratio of the two different hydraulic conductivities.

- The deeper the penetration of a canal into the lens, the greater hydraulic influence of the canal.

- Canals constructed further inland decrease the lens thickness and lessen the extent of the lens as compared to shorter canals.

- Reduction in the extent of island lenses reduces the quality and quantity of surface water bodies.

M.J. Wightman's *Geophysical Analysis and Mathematical Modeling of Freshwater Lenses on Big Pine Key, Florida*, 1990, thesis investigated why Big Pine Key had two freshwater lenses, which did not conform to findings of islands with a homogeneous distribution of hydraulic conductivity, in addition to performing flow net analysis. Findings from his thesis are summarized below:

- The absence of a freshwater lens in the middle portion of the island is due to the contact between the Miami and Key Largo Limestones closer to ground surface, and by drainage attributed to mosquito-control ditches.

- Utilizing the recharge method where the ratio of chloride concentration of rainfall to that of groundwater is directly proportional to the ratio of recharged to precipitation, Wightman calculated that 20 percent of precipitation is recharged to the groundwater system.

- Hydraulic conductivity of 400 feet/day was calculated for the Miami Limestone.

- Hydraulic conductivity of 4,000 feet/day was calculated for the Key Largo Limestone.

- Residence times determined by flow net analysis ranged from 1.65 years to 4.34 years with an average residence time of three years.

- Streamtube construction illustrated how the groundwater flow was primarily located in the lower Key Largo Limestone unit.

3.5.2   Resulting Data

Based on the ancillary investigations, the pertinent findings and data of the investigations are presented below.

- There is no continuous occurrence of a confining layer throughout the Florida Keys.

- The Upper Keys are composed of the Key Largo Limestone, while the Lower Keys consist of the Miami Limestone underlain by the Key Largo Limestone.

    – Key Largo Limestone is a white to tan limestone that is primarily the skeletal remains of corals, with marine debris and lime-sand. The Key Largo Limestone thickness can vary from about 75 feet to over 200 feet, and a geometric mean groundwater flow rate of 54 feet/day was calculated.

    – Miami (Oolite) Limestone is white to light tan, composed of tiny ooliths, lime-sand, and shells. Ooliths are made of concentric layers of calcium carbonate deposited around a nucleus of sand or shell. Miami Limestone thickness varies from a few feet to 35 feet, and a geometric mean groundwater flow rate of 8 feet/day was calculated.

- Subsurface geology and groundwater characteristics are largely undocumented for most of the Keys.

- For the majority of the Florida Keys, there are no freshwater lenses due primarily to the high porosity and hydraulic conductivity of the Key Largo Limestone.

- Data regarding tidal pumping indicates that tidal pumping is a transient phenomenon. Any long-term average of groundwater movement neglects the transient effects of tidal pumping.

- Limited freshwater lenses exist on Key West and Big Pine Key.

- Spatial location information for the vast majority of the pollutant sources is loosely tied to parcel locations, not specific geo-referenced coordinates, which is an approximate location.

- Specific wastewater treatment technologies and subsequent effluent disposal methods are undocumented for a significant number of parcels, even though the Sanitary Waste Master Plan has attempted to infer this information based upon the age of the existing structures.

- Phosphate concentrations decreased significantly a short distance from the source.

- Viral tracers indicated very rapid transport in the Key Largo Limestone.

3.5.3   Revised Component Formulation

Seasonal water table fluctuations may be a factor on several of the larger islands in the Keys, but data was not identified from any source for long-term water table fluctuation that would support a more complex analysis. The formulation of the Groundwater Component has been modified to accommodate this lack of data by using the assumption of steady-state conditions, i.e., no change in aquifer storage - wherein the water table elevation is constant with time.

The model formulation presented in DO 5 was also revised to eliminate the considerations of a confining unit or a significant freshwater lens underlying the islands in the Florida Keys based upon the results of the ancillary investigation. The two principal limestone units of the Florida Keys are the Miami Limestone and the Key Largo Limestone. For purposes of the Groundwater Component, the Florida Keys will be divided into two zones, the Upper Keys and the Lower Keys. The different hydraulic characteristics of the two limestone units are incorporated into the algorithms developed for the Groundwater Component.

Hydraulic Transport and Discharge Location

The idealized hydraulic transport of groundwater is that it follows the path of least resistance. Studies in the Florida Keys have shown the rapid transport of groundwater to the nearby canals and ocean. Flow net analysis and analytical calculations have indicated that groundwater discharge generally occurs along the shoreline, or in the nearshore environment, immediately adjacent to the shoreline.

The hydraulic transport rates are not being considered in the revised formulation since the pollutant treatment is not dependent upon time. The hydraulic transport times from on-site disposal systems to the surface waters has been measured to occur very quickly. However, the treatment reduction factors for particular pollutants are not time-dependent. Therefore, it is assumed that regardless of the transport time, pollutant mass introduced to the groundwater in a particular time step will either be reduced or remain unchanged, based on the treatment reduction, and then transferred to the Immediate Nearshore Waters Component within the same time step.

Pollutant Transport and Treatment

Initially, the following parameters were to be utilized in the Groundwater Component, Nitrogen, Phosphate, BOD TSS, pH, fecal coliform, Copper, Cadmium, Lead, and Zinc. Due to an assumed high entrapment of the TSS, and the inability to correlate the origin of the TSS, TSS will not be simulated. The parameter pH will also not be simulated, since very complex reactions govern the pH in groundwaters and trying to determine how the effluent with a specific pH reacts with groundwaters is not feasible without complex geochemical modeling. Due to the lack of any soil development in the Florida Keys, hence no significant organic carbon sources, the trace metals are assumed to have no sorption and thus no treatment reduction will be employed. Due to the rapid groundwater transport reported in field studies, BOD and fecal coliform will have a treatment reduction of zero. TN is assumed to remain conservative in the groundwater system (Lapointe and Clark, 1992), thus no treatment reduction will be employed.

Total phosphate will have a treatment reduction factor of 50 percent applied to its mass, since it was noted that the test site did not discharge as much as other sites and the higher discharge sites might not have the capacity to reduce the phosphate as much as 95 percent (D.R. Corbett, et al., 2000).

In summary, due to the lack of documented treatment rates in the Study Area and the reported rapid transport of leachate from on-site disposal system to surface waters, nitrogen, BOD, fecal coliform, Copper, Cadmium, Lead, and Zinc pollutant mass loads will not be reduced as the loadings are transported to the Immediate Nearshore Waters Component. However, based on the literature review, phosphate can either form a precipitate or sorb on to the limestone very easily. Thus, based on a removal rate calculated by Corbett, et al. (2000) of 95 percent within the 15 feet of the source, a conservative removal percentage estimate of 50 percent will be utilized to predict the total phosphate reduction within the groundwater system.

The shallow groundwater pollutant mass loadings will be allocated to specific wastesheds depending on the point of origin. The shallow groundwater loads simulated in the Groundwater Component for each wasteshed will be totaled. The wastesheds will then distribute these loads to the assigned adjoining elemental grid cells.

3.5.4   **Enabling Assumptions**

- To simplify the computational process, all of the individual wastestreams are aggregated into a single waste stream within the algorithms used in this (and other) components.

- From a hydrogeologic aspect, the Florida Keys are divided into two groups, the Upper Keys from Key Largo to Bahia Honda, and the Lower Keys from Big Pine Key to Key west.

- "Steady-state" groundwater flow conditions occur; that is, ambient conditions do not change with respect to time.

- Tidal pumping is not included in the current formulation of the Groundwater Component.

- Any wastewater effluent that enters a <u>shallow</u> disposal well (depth typically 60- 90 feet) is assumed to 1) rise in the groundwater underlying the Keys due to differential density, 2) move outward from the point of discharge toward the immediate nearshore waters due to the existing subsurface flow regime, 3) mix with the surficial portion of the groundwater, and 4) emerge in the immediate nearshore waters elements.

- Any wastewater effluent that enters a <u>deep</u> disposal well (depth greater than 2,000) is assumed to have left the groundwater system because it is discharged to a different groundwater regime that is not exchanging flow with the surficial portion of the aquifer underlying the Keys. Conceptually, some of the effluent could be discharged to the immediate nearshore waters due to geologic anomalies, but computationally it is eliminated (never to return to the surficial portion of the aquifer) in the current algorithm.

- There is no biological production of nutrients.

- All discharges arrive immediately in the proximity of the shoreline and can be idealized as being transferred to the immediate nearshore waters element closest to the shoreline.

- Flow paths, regardless of the point of origin within a wasteshed, are assumed to discharge at the shoreline of the wasteshed.

- Treatment reduction percentage of pollutant loads are based on available literature (transformation/fixation/binding processes).

- In the absence of literature documenting treatment, a "no treatment" condition will be assumed to exist in which no reduction occurs as the effluent moves to the immediate nearshore waters elements.

- Given the lack of accurate information on the location of disposal points for most of the wastestreams, the model assumed no distance effects.

3.5.5 Current Computational Algorithm

The algorithms that were developed for computing net pollutant loads to the Immediate Nearshore Waters Component were for net pollutant load exchange. Response of the groundwater discharge to the immediate nearshore waters from various pollutant sources (stormwater and wastewater) are handled by the Groundwater Component.

The Groundwater Component uses a customized load accounting system developed for the Upper and Lower Keys to estimate the loads transferred to the Immediate Nearshore Waters Component.

Stormwater pollutant loads are exported from the Stormwater Component (SWLOAD2GW) and a treatment reduction percentage for the unsaturated and saturated groundwater zones (GWSATTREAT and GWUNSATTREAT) is applied to the load for each wasteshed. Thus, pollutant loads are computed using the following formula:

SWLOADTREAT[n, d, y] = SWLOAD2GW[n, d, y]*GWSATTREAT[y]*GWUNSATTREAT[y]

Where: SWLOADTREAT [n, d, y] is the treated stormwater pollutant load (pounds)
SWLOAD2GW [n, d, y] is the stormwater load (pounds) from the Stormwater Component
GWSATTREAT [y] is the saturated groundwater treatment reduction factor
GWUNSATTREAT [y] is the unsaturated groundwater treatment reduction factor

y is the specific modeled pollutant
n is the given catchment
d is the specific day date during the simulation period

Wastewater pollutant loads exported from the Wastewater Component (WWLOAD2GW) and a treatment reduction percentage for the unsaturated and saturated groundwater zones (GWSATTREAT and GWUNSATTREAT) are applied to the load for each wasteshed. Thus, pollutant loads are computed using the following formula:

WWLOADTREAT [n, d, y] = WWLOAD2GW [n, d, y] * GWSATTREAT [y] * GWUNSATTREAT [y]

> Where: WWLOADTREAT [n, d, y] is the wastewater pollutant load (pounds)
> WWLOAD2GW [n, d, y] is the wastewater load (pounds) from the Wastewater Component
> GWSATTREAT [y] is the saturated groundwater treatment reduction factor
> GWUNSATTREAT [y] is the unsaturated groundwater treatment reduction factor

The sum of the stormwater loads and the wastewater loads are then computed for each wasteshed and transferred to the appropriate element grids. The following formula calculates the combined stormwater and wastewater loads:

GWLOAD2HZ [n, d, y] = SWLOADTREAT [n, d, y] + WWLOADTREAT [n, d, y]

> Where: GWLOAD2HZ [n, d, y] is the sum of the treated pollutant loads for each respective wasteshed

The stormwater volumes and the wastewater volumes are calculated for each wasteshed and the resultant volume is transferred to the appropriate element grids. The following formula calculates the combined wastewater and stormwater volumes:

GWVOL2HZ [n, d] = SWVOL2GW [n, d] + WWVOL2GW [n, d]

> Where: GWVOL2HZ [n, d] is the sum of the volumes (mgd) for each respective wasteshed
> SWVOL2GW [n, d] is the sum of the stormwater volumes (mgd) for each respective wasteshed
> WWVOL2GW [n, d] is the sum of the wastewater volumes (mgd) for each respective wasteshed

The shoreline flux rates will be calculated utilizing the GWVOL2HZ variable and the length of shoreline for each wasteshed. The following formula calculates the shoreline flux rate per wasteshed:

Q_{gw} [n ,d] = GWVOL2HZ [n, d] / LF

> Where: Q_{gw} [n, d] is the shallow groundwater shoreline flux rate (mgd/feet)
> LF is the linear feet of the wasteshed shoreline

3.5.6   Definition of Datasets

With the revised model formulation, the following representative dataset in Table 25 was needed to support the current model algorithms:

TABLE 25
TREATMENT REDUCTION FACTORS FOR
UNSATURATED AND SATURATED ZONES

	Net Removal Coefficient	
Constituent	**Unsaturated Zone**	**Saturated Zone**
Total Nitrogen	0%	0%
Total Phosphate	0%	50%
BOD	0%	0%
Fecal Coliform	0%	0%
Copper	0%	0%
Cadmium	0%	0%
Lead	0%	0%
Zinc	0%	0%

Treatment Reduction Percentage of Pollutant Loads

The treatment reduction factor was applied for the unsaturated and saturated zones of the groundwater system. The treatment reduction factor of 50 percent assumed for total phosphate is just for the saturated zone of the groundwater system. A treatment factor of zero was applied to the unsaturated zone due to lack of available data in the literature specific for the Florida Keys.

3.5.7   Integration Considerations

There are no significant integration considerations with the updated Component formulation. A GIS utility will be created to transfer the groundwater pollutant loads and volumes by wasteshed to the appropriate element grid by utilizing shoreline flux rates.

3.6   Disposal Wells Component

The Disposal Well Component is responsible for quantifying the time of travel and pollutant loads transported to the immediate nearshore waters from Class V wastewater disposal well discharges. This component is responsible for accumulating and quantifying, at the wasteshed level, the input volumes and pollutant loads generated by the on-site wastewater treatment system effluents, providing supplemental treatment, and discharging the accumulated volumes and net pollutant loads to the appropriate immediate nearshore waters elements for use by the Marine Module.

3.6.1   Ancillary Investigation Activities

The two principal limestone units that comprise the Florida Keys and receive disposal well discharges are the Miami Limestone and the Key Largo Limestone. For purposes of this investigation, the Florida Keys will be divided into two zones, the Upper Keys and the Lower

Keys. The Upper Keys consist of long linear islands from Key Largo to Bahia Honda that represent a reef tract formed during high sea levels of the last interglacial period (approximately 100,000 years ago) and are oriented parallel to the continental shelf. The larger, Lower Keys are composed of fossil oolithic limestone from Big Pine Key to Key West, which is oriented perpendicular to the shelf. The different hydraulic characteristics of the two limestone units are incorporated into the algorithms developed for the injection well module.

Investigation activities included conducting literature reviews from various agencies, books, and journals. Agencies such as the Florida Geological Survey, the FDEP, the Miami Geological Society, the SFWMD, the USGS, and the U.S. Environmental Protection Agency (USEPA) were contacted and available information regarding the Florida Keys were requested. Most of the investigation activities previously described in Section 3.5, Groundwater Component, are directly applicable to this component.

Florida Department of Environmental Protection

The FDEP regulates the permits issued to Class V disposal wells. The FDEP South District Office in Ft. Myers, Florida is in charge of reviewing the permits for the Florida Keys. Jack Myers of the Underground Injection Control Program is in charge of reviewing the permits and he was contacted by telephone for information regarding the disposal wells located in the Florida Keys.

Jack Myers said that up until 1999, there were no technical specifications required for Class V disposal wells in the Florida Keys because the groundwater underlying the Florida Keys is designated as G-III waters. Now, all wells have to be cased to 60 feet bls, with a minimum total depth of 90 feet bls.

An electronic dataset was acquired from the FDEP's Tallahassee office that listed all available injection wells for the Florida Keys. Data included well construction details, facility name and address, and latitude and longitude of the injection well location.

U.S. Geological Survey

The USGS has intensively studied the geology of the Florida Keys by conducting research for the past 20 years or more. The majority of the work has been focused on the recent declines of reef health that are located seaward of the Florida Keys. Much of this work is focused on the effects of the injection wells that dispose of wastewater into the underlying limestone. These data were presented in Section 3.6. E.A. Shinn of the USGS Marine and Coastal Geology Program (St. Petersburg, Florida) was contacted for further information regarding the geologic interpretations he has amassed from all of the projects he has conducted in the Florida Keys, in particular, the findings he reported in his USGS Open-File Report 94-276, *Fate and Pathways of Injection-Well Effluent in the Florida Keys*.

E.A. Shinn, et al. USGS Open-File Report 94-276, *Fate and Pathways of Injection-Well Effluent in the Florida Keys*, examined the corings and water quality analysis of 24 wells that were installed onshore and offshore of the Florida Keys. The key hydrogeologic findings in the report were:

- The Holocene mud sediments that cover the bottom of Florida Bay are the most significant confining bed in the offshore Florida Keys reef tract.

- Onshore and nearshore, where Holocene deposits are absent or thin, the very top of the limestone (just below land surface) is almost impermeable.

- Onshore and nearshore, between 25 and 35 feet deep, there is a leaky confining bed.

- The Pleistocene limestone is extremely porous and permeable.

- Tidal pumping diffuses, dilutes, and transmit fluids vertically.

- Test sites did not indicate the formation of a freshwater "bubble" surrounding the injection wells.

- Transects did not indicate that disposal well pollutant loads were responsible for nitrogen near the reefs; since ammonia concentrations were increasing towards the reef, just the opposite effect would be expected if the disposal wells were the source of nitrogen.

However, based on a personal communication with E.A. Shinn, subsequent borings did not indicate the widespread occurrence of a leaky confining bed. The occurrence of any onshore clay or low permeability deposits that behave as a confining unit are generally site specific. Shinn also believes that the ammonia measured at the reefs is possibly from underlying connate water under denitrification or ammonification conditions. He said that tidal pumping affects the nearshore environments and most likely disperses the pollutant loads before they reach the reefs.

Well Drillers

Based on information provided by Jack Myers of FDEP (Ft. Myers, Florida), Sickle Well Drilling drilled and constructed many of the injection wells in the Florida Keys. The Technical Contractor contacted the owner, Mr. Carl Sickle, and inquired about the geology he encountered while drilling injection wells in the Florida Keys.

The total depth of the majority of the wells ranged from 60 to 90 feet deep. Throughout both the Upper and Lower Keys, Carl Sickle indicated that limestone was the primary material penetrated; he did not encounter clay or any fine-grained material. He added that drilling through the Miami Limestone in Key West was very hard. Samples indicated no secondary porosity features and very low yields when tested under pumping conditions.

<u>**U.S. Environmental Protection Agency**</u>

We researched USEPA's online website for publications pertaining to the Florida Keys. A USEPA report by L.R. Kump, *Fate of Wastewater Nutrients in Florida Keys Groundwater*, 1998, concluded that phosphate is being immobilized within the Key Largo Limestone.

3.6.2   <u>Resulting Data</u>

Based on the ancillary investigations, the pertinent findings and data of the investigations are presented below.

- There is no continuous occurrence of a confining layer throughout the Florida Keys.

- The Upper Keys are composed of the Key Largo Limestone, while the Lower Keys consist of the Miami Limestone underlain by the Key Largo Limestone.

  – <u>Key Largo Limestone</u> is a white to tan limestone that is primarily the skeletal remains of corals, with marine debris and lime-sand. The Key Largo Limestone thickness can vary from about 75 feet to over 200 feet, and a geometric mean groundwater flow rate of 54 feet/day was calculated.

  – <u>Miami (Oolite) Limestone</u> is white to light tan, composed of tiny ooliths, lime-sand, and shells. Ooliths are made of concentric layers of calcium carbonate deposited around a nucleus of sand or shell. Miami Limestone thickness varies from a few feet to 35 feet, and a geometric mean groundwater flow rate of 8 feet/day was calculated.

- For the majority of the Florida Keys, there are no freshwater lenses due primarily to the high porosity and hydraulic conductivity of the Key Largo Limestone.

- Limited freshwater lenses exist on Key West and Big Pine Key.

- Phosphate concentrations decreased significantly a short distance from the source.

- Viral tracers indicated very rapid transport in the Key Largo Limestone.

3.6.3   <u>Revised Module Formulation</u>

The model formulation presented in DO 5 was revised to eliminate the considerations of a confining unit or a significant freshwater lens underlying the islands in the Florida Keys based upon the results of the ancillary investigation. The two principal limestone units of the Florida Keys are the Miami Limestone and the Key Largo Limestone. For purposes of the Groundwater Component, the Florida Keys will be divided into two zones, the Upper Keys and the Lower Keys. The different hydraulic characteristics of the two limestone units are incorporated into the algorithms developed for the Groundwater Component.

Hydraulic Transport and Discharge Location

The idealized hydraulic transport of groundwater follows the path of least resistance. Studies in the Florida Keys have shown the rapid transport of groundwater to the nearby canals and ocean. Flow net analysis and analytical calculations have indicated that groundwater discharge generally occurs along the shoreline, or in the nearshore environment, immediately adjacent to the shoreline.

The hydraulic transport rates are not being considered in the revised formulation since the pollutant treatment is not dependent upon time. The hydraulic transport times from on-site disposal systems to the surface waters have been measured to occur very quickly. Therefore, it is assumed that regardless of the transport time, pollutant mass introduced to the groundwater in a particular time step will either be reduced or remain unchanged, based on the treatment reduction, and then transferred to the Immediate Nearshore Waters Component within the same time step.

Pollutant Transport and Treatment

Initially, the following parameters were to be utilized in the Groundwater Component: nitrogen, phosphate, BOD, TSS, pH, fecal coliform, copper, cadmium, lead, and zinc. Due to an assumed high entrapment of the TSS and the inability to correlate the origin of the TSS, TSS will not be simulated. The parameter pH will also not be simulated, since very complex reactions govern the pH in groundwaters and trying to determine how the effluent with a specific pH reacts with groundwaters is not feasible without complex geochemical modeling. Due to the lack of any soil development in the Florida Keys, hence no significant organic carbon sources, the trace metals are assumed to have no sorption, thus no treatment reduction will be employed. Due to the rapid groundwater transport reported in field studies, BOD and fecal coliform will have a treatment reduction of zero. TN is assumed to remain conservative in the groundwater system (Lapointe and Clark 1992), thus no treatment reduction will be employed. Total phosphate will have a treatment reduction factor of 50 percent applied to its mass, since it was noted that the test site did not discharge as much as other sites and the higher discharge sites might not have the capacity to reduce the phosphate as much as 95 percent (Corbett, et al. 2000).

Due to the reported rapid transport of leachate from on-site disposal system to surface waters, nitrogen, BOD, fecal coliform, copper, cadmium, lead, and zinc pollutant mass loads will not be reduced as the loadings are transported to the Immediate Nearshore Waters Component. However, based on the literature review, phosphate can either form a precipitate or sorb on to the limestone very easily. Thus, based on a removal rate calculated by Corbett, et al. (2000) of 95 percent within the 15 feet of the source, a conservative removal percentage estimate of 50 percent will be utilized to predict the total phosphate reduction within the groundwater system.

The disposal well pollutant mass loadings will be allocated to specific wastesheds depending on the point of origin. The disposal well loads simulated in the Groundwater Component for each

wasteshed will be totaled. The wastesheds will then distribute these loads to the assigned adjoining elemental grid cells.

3.6.4 Enabling Assumptions

- From a hydrogeologic aspect, the Florida Keys are divided into two groups, the Upper Keys from Key Largo to Bahia Honda, and the Lower Keys from Big Pine Key to Key West.

- Subsurface conditions, from the bottom of the well to sea level, are uniform and are treated as a homogeneous limestone aquifer unit.

- "Steady-state" groundwater flow conditions occur which imply that ambient conditions do not change with respect to time.

- There is no biological production of nutrients.

- All disposal well effluents rise due to density differences with seawater, arrive at the approximate edge of the shoreline and can be idealized as transferring to the immediate nearshore waters element that is nearest to the shoreline.

- Treatment reduction percentage of pollutant loads are based on available literature (transformation/fixation/binding processes).

- In the absence of literature documenting treatment, a "no treatment" condition will be assumed to exist in which no reduction occurs as the disposal well effluents move to the immediate nearshore waters elements.

3.6.5 Current Computational Algorithm

The algorithms that were developed for computing net pollutant loads to the Immediate Nearshore Waters Component were comprised of net pollutant load exchanges. Response of the groundwater discharge to the immediate nearshore waters from disposal wells are handled by the Disposal Well Component. The Disposal Well Component uses a customized load accounting system developed for the Upper and Lower Keys to estimate the loads transferred to the Immediate Nearshore Waters Component.

Disposal Well pollutant loads are exported from the Wastewater Component (WWLOAD2DW) and a treatment reduction percentage for the saturated groundwater zone (GWSATTREAT) is applied to the load for each wasteshed. Thus, pollutant loads are computed using the following formula:

$$DWLOAD2HZ\ [n,\ d,\ y] = WWLOAD2DW\ [n,\ d,\ y]\ *\ GWSATTREAT\ [n,\ d,\ y]$$

Where: DWLOAD2HZ $[n,\ d,\ y]$ is the disposal well pollutant load (pounds)
WWLOAD2DW $[n,\ d,\ y]$ is the disposal well load (pounds) from the Wastewater Component
GWSATTREAT $[y]$ is the saturated groundwater treatment reduction factor
y is the specific modeled pollutant
n is the given catchment
d is the specific day date during the simulation period

The disposal well volumes are calculated for each wasteshed and the resultant volume is transferred to the appropriate element grids. The following formula calculates the disposal well volumes:

$$\text{DWVOL2HZ } [n, d] = \text{WWVOL2DW } [n, d]$$

Where: DWVOL2HZ $[n, d]$ is the sum of the volumes (mgd) for each respective wasteshed
WWVOL2DW $[n, d]$ is the daily wastewater pollutant volume (mgd) for each respective wasteshed

The shoreline flux rates will be calculated by the utilizing the DWVOL2HZ variable and the length of shoreline for each wasteshed. The following formula calculates the shoreline flux rate per wasteshed:

$$\text{Qdw } [n, d] = \text{DWVOL2HZ } [n, d] / \text{LF}$$

Where: $Q_{dw} [n ,d]$ is the disposal well shoreline flux rate (mgd/feet)
LF is the linear feet of the wasteshed shoreline

3.6.6   Definition of Datasets

With the revised model formulation, the following representative dataset was needed to support the current model algorithms:

Treatment Reduction Percentage of Pollutant Loads

The treatment reduction factor was applied for the saturated zones of the groundwater system and are shown in Table 26. The treatment reduction factor of 50 percent is assumed for total phosphate.

TABLE 26
TREATMENT REDUCTION FACTORS FOR THE SATURATED ZONE

Constituent	Net Removal Coefficient (Saturated Zone)
Total Nitrogen	0%
Total Phosphate	50%
BOD	0%
Fecal Coliform	0%
Copper	0%
Cadmium	0%
Lead	0%
Zinc	0%

3.6.7   Integration Considerations

There are no significant integration considerations with the updated Component formulation. A GIS utility will be created to transfer the disposal well pollutant loads and volumes by wasteshed to the appropriate element grid by utilizing shoreline flux rates.

3.7 Boating Discharges Component

The Boating Discharge Component quantifies the pollutant loads related to the residential, commercial, and recreational use of boats. The component utilizes estimates of boating populations from surveys and boater registrations. Estimates of loading rates were developed from previously published studies. All of this information will be used to estimate pollutant loads discharged to receiving waters.

The Boating Discharge Component performs the following basic functions:

- Computes pollutant loads for BOD from LABs that are located at marinas and anchorages.
- Proportions and routes the computed pollutant loads to the Immediate Nearshore Waters/Circulation Components.

3.7.1 Ancillary Investigation Activities

Data investigation activities focused on the identification and collection of data regarding boating activities, which could be quantified into an algorithm for implementation into the CCAM. Sources of information that were consulted included Monroe County, the FDEP, the Florida Department of Motor Vehicles (DMV), the Florida Marine Research Institute (FMRI), Internet searches and library searches. Although an enormous amount of information was located regarding boats and boat impacts, very little quantifiable data was found on which to base pollutant load estimates. Most of the quantifiable data consisted of the numbers and locations of boats and their seasonal variations.

Monroe County

In 1994, Monroe County undertook a project that resulted in a report, *Development of a Comprehensive Boat Channel Marking Plan for the Florida Keys*. One of the tasks undertaken was the identification and geo-referencing of both permitted and un-permitted navigational aids. The resulting data file identified areas of high boat traffic. No data related to the generation of pollutants by boat traffic was identified. Boat traffic information may be useful for estimating impacts to sea-grasses, but cannot currently be used to model water quality impacts.

A second task in the project was the characterization of navigational access points. This included a survey of all of the marinas and anchorages within the Keys. The resulting marina inventory included a thorough listing of facilities available at each marina. Some of the information that was collected included: 1) type of facility; 2) primary activities; 3) length of largest vessel; 4) availability of restrooms, fuel, engine repair, hull repair, groceries, pump-out facilities; 5) the number of wet and dry slips; 6) type of boats normally accommodated; and others.

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Information from the anchorage inventory included the type of craft that predominately use the anchorage, the approximate size of the anchorage in acres, and whether LABs use the anchorage and their numbers.

These two inventories were updated based on other marina lists and data sources to compile a master marina inventory for use in the Boating Discharge Component.

Florida Department Environmental Protection

The FDEP operates a number of programs and disseminates information to educate boaters and marina operators for utilizing the BMPs necessary to keep pollution out of waterways. Most of the information is qualitative and cannot be used to quantify pollutant loads or removal by the use of these BMPs. Information collected from FDEP, which has the potential for inclusion in the Boating Discharge Component, includes pump out data and a marina inventory.

Pump Out Data

The Clean Vessel Act (CVA) of 1992 provides funds for the construction of pump-out and dump station facilities as well as providing funds for educational public awareness programs such as the ones mentioned above. The following list of marinas were granted funds by the CVA to install pump-out facilities:

- Garrison Bight Channel,
- Marina at Key Largo,
- Smuggler's Cove Marina,
- Sunshine Key Resort Park,
- Coral Bay Marina,
- Key Colony Beach Marina,
- John Pennekamp Coral Reef State Park,
- Key West Conch Harbor,
- Bayside Marine,
- Key West Bight Marina,
- Safe Harbour Marina,
- Marathon Yacht Club, and
- Marathon Community Marina.

The installation of pump-out facilities has for the most part been completed. FDEP collects information from these marinas on a quarterly basis including the total number of vessels served, the number of out of state vessels, the quantity of waste removed, and the fees associated with the use of the facility. This pump-out data was requested from the FDEP, but has not been received at the time of this writing. Depending on the level of detail available, the pump-out

data may be included in the Boating Discharge Component and developed into input variables to the Wastewater Component.

Marina Inventory

FDEP collected information on marinas throughout the State of Florida including those located in Monroe County. The inventory included: 1) name and address of the marina; 2) phone number; 3) number of slips; 4) location (latitude and longitude); and 5) the existence of fuel, pump-out, dump station, and toilet facilities. This was combined with the Monroe County master inventory to form the master marina list.

Department of Motor Vehicles

Boat ownership in Florida requires the registration of every vessel. The DMV maintains registration data on boats within each county. The records of over 25,000 registered boats in Monroe County were obtained from the DMV. The registration records include information on the owner (individual or business), owner's name and address, vehicle make and year, fuel type, propulsion type, gross and net weight, and the length and width of the vessel.

Although wastewater is considered a major source of pollution from boats, information on sanitary facilities is not included in the DMV records. State law requires any vessel 26 feet or longer with an enclosed cabin and berthing facility to have a working toilet on board. An estimate on the number of vessels with sanitary facilities can be made by assuming that all large vessels have such facilities. This neglects the fact that some smaller vessels do have sanitary facilities, but the percentage of these is unknown.

Many of these vessels are inactive for a majority of time. It was estimated by the International Marina Institute that on a normal summer weekend, only 25 percent of boats at marinas would be used. During weekdays, this ratio is expected to fall under 10 percent. These estimates were based on the boat season.

While a "percentage of use" is given for boats at marinas, the literature search did not reveal what percentage of all boats, including those not located at marinas, is used at any given time. In addition, the percentage of use is only applicable for boats in marinas during the boating season and is not applicable during the off-season. For these reasons, the DMV's boat registration information cannot be readily used for defensible computation purposes in the Boating Discharge Component.

Florida Marine Research Institute

The FMRI provided several data tables including a marina inventory, boat counts and seasonal variations.

Marina Inventory

FMRI provided a list of approximately 170 marinas. This information was compiled with the Monroe County and FDEP data to develop the master inventory.

<u>Boat Count</u>

FDEP and the Nature Conservancy sponsored efforts to estimate the number of boats operating in the Florida Keys National Marine Sanctuary (FKNMS). From June 1992 until August 1993, FMRI conducted over 50 aerial surveys, supplemented by surface surveys, to count and classify boats in the FKNMS.

Sampling days were selected at random within five categories, summer weekdays, summer weekends, winter weekdays, winter weekends, and "special event" days (Memorial Day, July 4th, recreational lobster season, opening of regular lobster season, and Labor day). Boats were categorized according to the following:

- Size (greater or less than 30 feet),
- Activity (diving, fishing, trapping),
- Movement (anchored, underway), and
- Type (motor, sail, personal watercraft).

The resulting GIS file contains the information from the aerial surveys. With the exception of LABs, no quantifiable data to link boats with pollution has been identified and the boat count information could not be implemented in the Boating Discharge Component.

<u>Seasonal Data</u>

Because the boat count data was collected over the course of a year, seasonality data might be extracted from the data. At least one such extraction has been performed by Dr. Ray A. Souter (Rork Associates) in a study titled *Review of Florida Marine Research Institute (FMRI) Aerial Fly-Over Methods for Estimating the Number and Type of Users in the Specially Protected Areas and Ecological Reserves of the Florida Keys National Marine Sanctuary*. In the study, boat abundance curves were developed to link the aerial count of boats and the total number of boats utilizing all sites. The study concluded that there was no difference in the aggregate activity patterns, but the average trip duration, number of users per boat and the total use based on the number of boats did differ seasonally. Winter daily boat-hours were roughly half that of summer daily boat-hours indicating boat counts were substantially different.

<u>Literature Survey</u>

Several articles were located that documented the effects that boats have on water quality. The reports and studies discussed below have the greatest potential for inclusion in the Boating Discharge Component. While they contained information on water quality impacts, only one of these studies was used in the development of the boating module.

Boat Live-Aboards in the Florida Keys: A New Factor in Waterfront Development, by G.A. Antonini, L. Zobler, H. Tupper, and R. Ryder.

This report was the only source of quantifiable data between boats and the generation of pollutants. The study focused on determining the special service needs of Florida Keys LABs.

Various field and direct mail surveys, opinion polls, or other means were conducted from November 1988 through July 1989. The information describes the spectrum of live-aboard lifestyles and behavior patterns of adjacent land residents toward water residents.

Included in the collected information were population estimates of LABs and boaters, vessel location, travel cycles, income and expenditure information, employment, and service requirements. Of particular interest to the Water Component is the information on seasonal population fluctuations as well as waste disposal methods used on LABs.

The report presents a figure representing the number of LABs found in the Florida Keys during the year that data was collected. This figure shows the seasonal fluctuations in the number of LABs at anchorages, and at seaside facilities such as marinas. In addition, a list of anchorages containing the results of a field survey of monthly boat counts is provided in the report by Antonini, et al.

Several assumptions were made to determine the BOD generated by each LAB. Based on the survey information, it is estimated that the number of residents per live-aboard household equals 1.8 persons per boat. A generalized constant is given for the average oxygen required to assimilate one person's sanitary waste per day; dimensions are 0.76 kilograms of oxygen per person per day. Pretreatment coefficients, estimates of the capacity of each boat to reduce the level of oxygen demand, is also presented. These coefficients will be discussed in later sections.

The Effects of Marinas and Boating Upon Tidal Waterways – R. Klein

Mr. Klein conducted a literature review on the effects of boating activity and related facilities upon tidal creeks. The review primarily addresses the effects of boating upon wetlands, submerged aquatic vegetation (SAV), bottom dwelling communities, and fish. Various studies found that boat propeller turbulence produced an increase in light attenuation by suspended sediments when the water depth was less than 2 meters. Reduction in productivity of SAV was also measured in these reports. Several researchers determined the effects of wakes produced by boats passing within 150 meters of a shoreline. Erosion and disturbance of emergent wetlands, and benthic invertebrates was quantified.

Several sources were cited regarding boat waste discharges. A Maryland survey conducted in the late 1970's indicated that two thirds of registered boaters with toilet facilities discharge wastes into the water. A USEPA 1985 estimate stated that a typical boat might release 130 million coliform bacteria during each hour of operation.

Another EPA source, *Coastal Marinas Assessment Handbook* (USEPA 1985) presented figures that indicate a boat releases 5 grams (0.01 pounds) of BOD during each hour of operation. This publication was unavailable for review and is apparently a 300-page microfiche document at the Universities of Florida and Florida State. A copy of the document could not be obtained and without further review could not be used in linking BOD and boat operation.

Water Quality Concerns in the Florida Keys: Sources, Effects, and Solutions – W.L. Kruczynski

The report summarized the water quality concerns in the Keys and discussed several sources and possible solutions. The report stated that the number of live-aboards in the Key West Area increased from 235 in 1992 to 393 in 1995. It was also stated that approximately 400 anchored or moored vessels occupied Boot Key Harbor in February of 1995.

The report estimated that nutrients from vessel wastewater account for 2.8 percent of nitrogen and 3.0 percent of phosphorous loadings into nearshore waters of the Keys, and that loadings from vessels are a significant nutrient source to harborages and result in eutrophication of waters with poor circulation or flushing. No sources of data were provided in support of this assertion.

Pollution Impacts from Recreational Boating – A.S. Milliken and V. Lee

This report provides some pollutant loading factors on a per boat basis. Data on the concentrations of typical wastewater were compared with the concentration of wastewater from boats (Coastal Marinas Assessment Handbook, USEPA 1985). An equation developed by the Food and Drug Administration (FDA) for the National Shellfish Sanitation Program (NSSP) is used to estimate the number of fecal coliforms from boats for use as the basis to determine the maximum allowable number of boats that can be located in a marina.

Valid criticisms of these were made in a paper by N. Ross titled *Toward a Balanced Perspective on Boat Sewage*. The assumptions used in the dilution analysis proposed by the U.S. Interstate Shellfish Sanitation Conference "Marina Policy" (essentially the same as the equation developed by the FDA for the NSSP) were criticized as unrealistic and overly conservative, yielding exaggerated sewage-loading factors. These loading factors are not included in the Boating Discharge Component.

The Contribution of Recreational Boats to Bacterial Water Pollution: A Model for Determining Sewage Loading Rates – M.E. Eldredge

This study attempted to modify the FDA/NSSP equation, focusing on adjusting the original assumption of 100 percent occupancy rate. A survey conducted in selected Rhode Island marinas to determine sewage loading factors on two high use weekends, July 4th and Labor Day, found that the occupancy rate ranged from 27 percent to 51 percent. Some evidence of a correlation between occupancy rates with boat length was also identified. Two modified forms of the FDA/NSSP equation were proposed to account for occupancy rates. The information cannot be used due to a lack of spatial and temporal distribution of boats.

A Comparison of Water Quality at Two Recreational Marinas During a Peak Use Period – J.S. Fisher, R.R. Perdue, M.F. Overton, M. Sobsey, and B.L. Still

The study found that fecal coliform levels in marinas became elevated during periods of high boat occupancy and usage. It also examined the effects of mixing upon coliform concentrations.

Vernon R. Leeworthy and Peter C. Wiley undertook a considerable study to characterize the activities engaged in by visitors to the Florida Keys, including boating activities. Surveys were conducted from June 1995 through May 1996. The number of visitors from June 1995 to May 1996 totaled approximately 2.5 million. Of these, 14.4 percent used their own boat, with a significantly higher proportion during the summer season (22.5 percent in the summer, 7.6 percent in the winter). The report included tables of the type of activity and a breakdown of winter vs. summer months. There were no quantitative assessments of the number of boats or their spatial locations.

3.7.2   Resulting Data

Boating Population

Several sources were used to identify the locations and numbers of boats in the Florida Keys. These sources include the DMV, FMRI, FDEP, Monroe County, several research documents, and the yellow pages.

The FDMV identified all registered boats in Monroe County. The records of over 25,000 registered boats were obtained. These records include information on the type of owner whether individual or business, the registrants name and address, the vehicle make and year, fuel type, propulsion type, gross and net weight, and the length and width of the vessel.

FMRI, FDEP, and Monroe County marina inventories were used to develop a master inventory of marinas and anchorages in the Florida Keys. This inventory identifies over 750 marinas and anchorages in the Florida Keys. FMRI also provided a set of shape files that identified the U.S. Coast Guard channel markers. This identifies the boating traffic areas. From June 1992 until August 1993, FMRI conducted over 50 aerial surveys, supplemented by surface surveys, to count and classify boats in the FKNMS.

Live Aboard Boats

The Antonini report determined that 1,410 live aboard boats (LABs), housing almost 3,000 people, existed in the Florida Keys. Of this population, 186 boats were surveyed. Several aspects of waste generation and disposal were examined. Solid waste generation varied by boat type with powerboats producing 143.2 gallons (in the form of plastic bags using dumpster facilities), compared with 103.1 for sailboats and 90.0 for floating homes. The average live aboard occupant disposed of 113.5 gallons of garbage per week. These numbers vary slightly based on location with the Upper Keys having the highest level (128.7 gal).

LAB population was found to be seasonal with the highest population occurring in the winter months. The report presented data on the monthly distribution of the number of LABs. The numbers of LABs were separated into three categories: seasonal shoreside facilities, resident shoreside facilities and seasonal anchorages. Table 27 shows the monthly distribution of the shoreside LABs.

TABLE 27
MONTHLY DISTRIBUTION OF SHORESIDE LIVE ABOARD BOATS

Month	Seasonal Shoreside	Year-Round Shoreside	Total Shoreside
January	220	210	430
February	185	215	400
March	132	204	336
April	80	199	279
May	65	210	275
June	60	205	265
July*	60	205	265
August*	45	178	223
September	45	178	223
October	102	181	283
November	110	179	289
December	180	203	383

* Monthly data value extrapolated.

Some of the monthly data presented in the Antonini report was missing (July and August). June data was used for July, and September data was used for August. A single normalized curve was developed from the monthly data to represent the shoreside LABs. Table 28 presents the normalized data for LAB numbers at marinas.

The locations of live-aboard anchorages were identified by a set of plans that was included with the Antonini report. These anchorages were identified and located by a dashed polygon. These polygons were digitized and associated with a unique identification number.

As mentioned previously, the Antonini report includes the monthly LAB count at certain anchorages and seawall tie-up locations. A table found in the report divides anchorages by their general location, i.e., the Lower, Middle, and Upper Keys. The anchorage LAB monthly population data for the Lower, Middle, and Upper Keys is presented in Tables 29, 30, and 31, respectively.

TABLE 28
NORMALIZED DISTRIBUTION OF SHORESIDE LIVE ABOARD BOATS

Month	Seasonal Shoreside	Year-Round Shoreside	Total Shoreside
January	100.00%	97.67%	100.00%
February	84.09%	100.00%	93.02%
March	60.00%	94.88%	78.14%
April	36.36%	92.56%	64.88%
May	29.55%	97.67%	63.95%
June	27.27%	95.35%	61.63%
July	27.27%	95.35%	61.63%
August	20.45%	82.79%	51.86%
September	20.45%	82.79%	51.86%
October	46.36%	84.19%	65.81%
November	50.00%	83.26%	67.21%
December	81.82%	94.42%	89.07%

TABLE 29
MONTHLY DISTRIBUTION OF ANCHORAGE LIVE ABOARD BOATS
(LOWER KEYS)

Anchorage ID	Christmas Tree Island 91	Garrison Bight 93	Houseboat Row 89	Cow Key Channel 90	Boca Chica Channel 92	Pine Channel 88
January	*22	*31	*20	*36	*19	*11
February	15	27	20	33	*17	10
March	31	37	18	45	25	18
April	33	40	20	46	20	16
May	29	39	21	44	22	12
June	38	26	21	42	15	15
July	30	20	21	50	10	14
August	*26	*24	*20	*41	*14	*12
September	21	*27	18	31	*17	9
October	24	*30	20	33	*19	9
November	31	*35	20	42	*22	8
December	29	*34	20	38	*21	12

* Monthly data value extrapolated.

TABLE 30
MONTHLY DISTRIBUTION OF ANCHORAGE LIVE ABOARD BOATS
(MIDDLE KEYS)

Anchorage ID	Boot Key Harbor 87	Key Colony Beach 86
January	*225	*7
February	250	6
March	225	4
April	180	3
May	110	6
June	100	7
July	82	9
August	*61	*7
September	40	4
October	65	7
November	150	6
December	200	7

* Monthly data value extrapolated.

TABLE 31
MONTHLY DISTRIBUTION OF ANCHORAGE LIVE ABOARD BOATS
(UPPER KEYS)

Anchorage ID	Matecumbe Harbor	Islamorada	MM 84.5 Bayside	Community Harbor	Largo Sound	Cross Key	Card Sound Bridge
	85	84	95	83	94	82	81
January	1*	9*	9*	7*	7*	7*	4*
February	0	10	10*	7	7*	8	4
March	0	9	6	5	5	5	4
April	2	4	14	13	10	6	4
May	1	15	9	14	9	2	4
June	1	16	12	11	9	0	4
July	1	18	14	14	9	5	4
August	1	12	10	10	7	4	4
September	0	6	6*	6	4*	2	4
October	0	4	5*	5	3*	1	4
November	1	5	7*	6	5*	4	4
December	1	8	8*	7	6*	5	4

* Monthly data value extrapolated.

With the exception of Garrison Bight, Boca Chica, MM 84.5 Bayside, and Largo Sound, data for the month of January was taken as the average of December and February. Likewise, with the noted exceptions listed above, data for the month of August was taken as the average of July and September for each respective location.

Data for Garrison Bight, Boca Chica, MM 84.5 Bayside, and Largo Sound presented in Tables 26 through 28, were developed utilizing the normalized curves developed from the information presented in Table 15 of the Antonini report. Table 32 shows the development of the normalized curves. Monthly boat counts are totaled for each region. Normalized values for each month are derived based on the maximum number of boats. To determine missing data, these normalized values are multiplied by the maximum number of boats found at a particular anchorage.

It was evident that some of the information in the Antonini report was missing. Some monthly data values from Garrison Bight, Boca Chica Channel, MM 84.5 Bayside and Largo Sound anchorages are not presented in the Antonini report. As a result, subsequent calculations were based on those locations that have at least 10 months of field records. A normalized seasonal curve was developed from the remaining anchorages for each of the three representative locations (Lower, Middle, Upper Keys). The normalized data is used to estimate the number of LABs at an anchorage based on the maximum number of boats expected at the anchorage and its location in the Keys. Table 33 presents a series of three curves for the monthly distribution of LABs in the Lower, Middle and Upper Keys.

TABLE 32
NORMALIZED BOAT COUNTS FOR THE STUDY AREA

	Field Survey Monthly Boat Count*											
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Lower Keys												
Christmas Tree Island	21	24	31	29	22	15	31	33	29	38	30	26
Garrison Bight	27	30	35	34	31	27	37	40	39	26	20	24
Houseboat Row	18	20	20	20	20	20	18	20	21	21	21	20
Cow Key Channel	31	33	42	38	36	33	45	46	44	42	50	41
Boca Chica Channel	17	19	22	21	19	17	25	20	22	15	10	14
Pine Channel	9	9	8	12	11	10	18	16	12	15	14	12
Lower Keys Subtotal	79	86	101	99	89	78	112	115	106	116	115	99
Normalized Seasonal Curve **NORMLABAL[m]**	0.681	0.741	0.871	0.853	0.767	0.672	0.966	0.991	0.914	1.000	0.991	0.853
Middle Keys												
Boot Key Harbor	40	65	150	200	225	250	225	180	110	100	82	61
Key Colony Beach	4	7	6	7	7	6	4	3	6	7	9	7
Middle Keys Subtotal	44	72	156	207	232	256	229	183	116	107	91	68
Normalized Seasonal Curve **NORMLABAM[m]**	0.172	0.281	0.609	0.809	0.906	1.000	0.895	0.715	0.453	0.418	0.355	0.266
Upper Keys												
Matecumbe Harbor	0	0	1	1	1	0	0	2	1	1	1	1
Islamorada	6	4	5	8	9	10	9	4	15	16	18	12
M.M. 84.5 Bayside	6	5	7	8	9	10	6	14	9	12	14	10
Community Harbor	6	5	6	7	7	7	5	13	14	11	14	10
Largo Sound	4	3	5	6	7	7	5	10	9	9	9	7
Cross Key	2	1	4	5	7	8	5	6	2	0	5	4
Card Sound Bridge	4	4	4	4	4	4	4	4	4	4	4	4
Upper Keys Subtotal	18	14	20	25	28	29	23	29	36	32	42	30
Normalized Seasonal Curve **NORMLABAU[m]**	0.429	0.333	0.476	0.595	0.667	0.690	0.548	0.690	0.857	0.762	1.000	0.714

* Data values that are highlighted were normalized to estimate values for months missing in the Antonini report –
all other values are presented as found in the Antonini report.

TABLE 33
NORMALIZED DISTRIBUTION OF ANCHORAGE LIVE ABOARD BOATS

Month	Curve 1 Lower Keys	Curve 2 Middle Keys	Curve 3 Upper Keys
January	76.72%	90.63%	66.67%
February	67.24%	100.00%	69.05%
March	96.55%	89.45%	54.76%
April	99.14%	71.48%	69.05%
May	91.38%	45.31%	85.71%
June	100.00%	41.80%	76.19%
July	99.14%	35.55%	100.00%
August	85.34%	26.56%	71.43%
September	68.10%	17.19%	42.86%
October	74.14%	28.13%	33.33%
November	87.07%	60.94%	47.62%
December	85.34%	80.86%	59.52%

The missing monthly data was estimated by multiplying the normalized curve value for a particular month by the maximum number of LABs observed for the anchorage. For example, Garrison Bight was missing data for September. A maximum of 40 LABs were found in April. It was estimated that 27 (40 x 0.681 = 27) LABs would be found at that anchorage for the month of September.

In addition to missing data at anchorages, data for the months of January and August was not collected for any of the anchorages. Data for these two months were determined by the average of the preceding and following months.

3.7.3   Revised Component Formulation

The previous identification of variables for the Boating Discharge Component was based on a conceptual approach and assumed that all possible data existed. In the pursuit of available data, it was found that a number of different variables could not be addressed given the proposed time scale and the lack of sufficient or adequate data to describe and characterize the variable.

The Boating Discharge Component computes pollutant loads from LABs based on the estimated number of boats and a characteristic pollutant-loading rate. Pollutant loads are accumulated from LABs located at anchorages and marinas and are outputs to the Immediate Nearshore Waters and Circulation Components. The input and output variables incorporated in the revised Boating Discharge Component are defined in the following paragraphs.

Input Variables

- MARINADD $[n]$ = estimated percentage of LAB within a particular marina (n) that directly discharge untreated wastewater.

- MARINAHT $[n]$ = estimated percentage of LAB within a particular marina (n) that use a holding tank prior to discharge.

- MARINAMC $[n]$ = estimated percentage of LAB within a particular marina (n) that use a macerator and chlorine disinfection prior to discharge.

- MARINAPO $[n]$ = estimated percentage of LAB within a particular marina (n) that use a marinas pump out facility without discharge to waters.

- OCCM $[m]$= occupancy rate of marinas. This is the percentage of wet slips that are occupied by all boats during a particular month (m) of the year.

- LABPERM $[m]$ = percentage of boats in the marina that are LABs during a particular month (m) of the year.

- ANCHORMAX $[n]$ = dataset of the anchorages containing the maximum number of LABs that can be found at any particular anchorage found within anchorage (n).

- ANCHORDD $[n]$ = estimated percentage of LAB within a particular anchorage (n) that directly discharge untreated wastewater.

- ANCHORHT [*n*] = estimated percentage of LABs within a particular anchorage (*n*) that uses a holding tank prior to discharge.

- ANCHORMC [*n*] = estimated percentage of LABs within a particular anchorage (*n*) that uses a macerator and chlorine disinfection prior to discharge.

- ANCHORPO [*n*] = estimated percentage of LABs within a particular anchorage (*n*) that use a marina pump out facility without discharge to waters.

Input Constants

- NORMLABM [*m*] = Normalized distribution describing the seasonal variations of LAB found at all marinas. A value between 0 and 1 is assigned to a particular month (*m*) of the year. This number represents a percentage of the maximum number of LABs found at any marina.

- NORMLABAU [*m*] = Normalized distribution describing the seasonal variations of LAB found at anchorages within the Upper Keys. A value between 0 and 1 is assigned to a particular month (*m*) of the year. This number represents a percentage of the maximum number of LABs found at a particular anchorage in the Upper Keys.

- NORMLABAM [*m*] = Normalized distribution describing the seasonal variations of LABs found at anchorages within the Middle Keys. A value between 0 and 1 is assigned to a particular month (*m*) of the year. This number represents a percentage of the maximum number of LABs found at a particular anchorage in the Middle Keys.

- NORMLABAL [*m*] = Normalized distribution describing the seasonal variations of LAB found at anchorages within the Lower Keys. A value between 0 and 1 is assigned to a particular month (*m*) of the year. This number represents a percentage of the maximum number of LABs found at a particular anchorage in the Lower Keys.

- MARINAWS [*n*] = Data table showing the number of wet slips for a particular marina (*n*).

- BOATPOPLAB* = Number of people per LAB (1.8 people per boat).

- LOADRATELAB* = BOD loading rate per person per day (1.675 pounds BOD/person/day) for LAB.

- CURVESA [*pu, cu*] = Data table determining which normalized distribution curve (*cu*) to use based on which wastewater planning unit (*pu*) it is in.

- CDDLAB* = Pretreatment reduction coefficient based on direct discharge (C=1).

- CHTLAB* = Pretreatment reduction coefficient based on a holding tank prior to discharge (C=0.5).

- CMCLAB* = Pretreatment reduction coefficient based on macerator and chlorine disinfection prior to discharge (C=0.3).

- CPOLAB* = Pretreatment reduction coefficient based on use of pump out facility (C=0.0).

*Provided in Appendix H of the Antonini Report

Output Variables

- MAXLABM [*n, m*] = Maximum number of LAB at a particular marina (*n*) in a specified month (*m*).

- MAXLABA [*n, m*] = Maximum number of LAB at a particular anchorage (*n*) in a specified month (*m*).

- CWTM [*n*] = Pretreatment reduction coefficient weighted to account for estimated percentages of pretreatment options for LAB at marinas (*n*).

- CWTA [*n*] = Pretreatment reduction coefficient weighted to account for estimated percentages of pretreatment options for LAB at anchorages (*n*).

- LABM [n, m] = Number of LABs in each marina (*n*) for a specified month (*m*).

- LOADLABM [*n, m*] = Daily pollutant load of BOD discharged per day during a particular month (*m*) of the year from LAB in marinas to a given circulation grid cell (*n*).

- LOADLABA [*n, m*] = Daily pollutant load of BOD discharged per day during a particular month (*m*) of the year from LAB at anchorages (*n*) to a given circulation grid cell (*n*).

3.7.4   **Enabling Assumptions**

It was assumed that the average population of 1.8 people per LAB has not changed since the Antonini report. Antonini obtained this value through a survey of 186 LABs.

The Antonini report does not specify where the values k and C come from. They were used in the Boating Discharge Component as presented in the report.

Some of the data tables presented in the Antonini report had missing values. For example, the data for January and August was missing for shoreside live aboards. January data was taken as the average of the previous and following months. September data was duplicated for August because it represents the slow summer season when the live aboard population is low.

The distribution of onboard waste practices among the types represented by the four C values is entirely unknown. Estimates of the distribution should be based on field observation. The conservative "worst case" scenario is to assume that all LABs directly discharge into the water with no holding tank (C = 1).

3.7.5 **Current Computational Algorithm**

The Antonini report included an appendix that addressed sanitary sewage discharged by LABs. A simple equation was presented to estimate the BOD pollutant load based on the boating population:

$$BOD \ (pounds/day/boat) = BP * k * C$$

Where: BP = boat population (number of people on LABs). The average population from the study was 1.8 persons/boat.

k = average oxygen to assimilate one person's sanitary waste per day (1.675 pounds/day).

C = boat coefficient to estimate the pre-treatment capacity of each boat in reducing the level of BOD:
  C = 1 none (direct discharge)
  C = 0.5 (onboard holding tank)
  C = 0.3 (onboard macerator with chlorination)
  C = 0.0 (discharge to a pump out facility)

Data on the number of LABs by pretreatment method was not provided and could not be developed from other sources.

Loads from LABs are divided into two categories: shoreside and anchorages. Shoreside LABs are those that reside at marinas and may or may not utilize the facilities of the marinas. Anchorages are typically away from the shoreside or in some instances may be tied up against a seawall.

Once an estimate of the number of boats is made, loading rates are then determined using the load equation. Pretreatment reduction factors are based on an estimated percentage of each type of pretreatment method in use. Estimates for these percentages should be based on field observation. The most conservative case would be to estimate that 100 percent of LABs directly discharge into the anchorage without a holding tank (C = 1).

Anchorage Live Aboard Boats

Populations of LABs located at anchorages are determined using the normalized monthly curve data NORMLABL [m] = Curve 1, NORMLABM [m] = Curve 2, NORMLABU [m] = Curve 3, and the anchorage inventory that lists the maximum number of boats expected at each anchorage ANCHORMAX [n]. The monthly values for the number of boats at each anchorage are determined by multiplying the annual maximum number of LABs by the appropriate normalized curve data shown previously in Table 30.

The algorithm for the number of LABs at anchor LABA [n, m] is

$$LABA \ [n, \ m] = NORMLABA\# \ [m] * ANCHORMAX \ [n]$$

The user makes adjustments to the maximum number of LAB at each anchorage ANCHORMAX [n]. Multiplied by the seasonality curve, the algorithm automatically estimates the monthly values LABA [n, m].

The # in NORMLABA#[m] represents a wildcard character, depending on whether the anchorage is in the Upper (U), Middle (M), or Lower (L) Keys. Based on the location of the anchorage, the dataset CURVESA [pu, cu] determines the correct curve.

Loading rates are determined from the following algorithm

LOADLABA [n, m] = BOATPOPLAB * LOADRATELAB * CWTA [n] * LABA [n, m]

Where: LOADLABA [n, m] = Anchorage BOD loading rate (pounds/day)
BOATPOPLAB = 1.8 persons per boat
LOADRATELAB = 0.76 kg BOD/person/day *
CWTA [n] = Weighted pretreatment reduction coefficient for anchorages
LABA [n, m] = # of LAB
*Provided in Appendix H of the Antonini Report

In order to determine CWTA [n], estimates on the types and quantities of the pretreatment facilities on board LAB must be made.

CWTA [n] = CDDLAB * ANCHORDD [n] + CHTLAB * ANCHORHT [n] + CMCLAB * ANCHORMC [n] + CPOLAB * ANCHORPO [n]

The input constants CDDLAB, CHTLAB, CMCLAB, and CPOLAB, were described in the Section 3.7.3 as being the reduction coefficient for each pretreatment methodology.

The input variables ANCHORDD [n], ANCHORHT [n], ANCHORMC [n], and ANCHORPO [n] are estimates, in percentage, of each pretreatment methodology used by LABs at each anchorage.

Shoreside Live Aboard Boats

This part of the boat module will determine BOD loadings from LABs that are located in marinas. The BOD loading rates from LABs located at anchor is determined in four steps. First, a normalized distribution NORMLABM[m] showing the seasonality of LABs at marinas was determined. NORMLABM [m] is used as an input constant to develop the monthly LABs population. Second, the maximum number of LABs per month MAXLABM [n, m] is determined for each marina and is determined from 1) the total number of wet slips available at each marina MARINAWS [n], 2) an estimate of the occupancy rate for all boats OCCM [m], and 3) an estimate of the percentage of boats that are live-aboards LABPERM [m]. The third step was to determine the number of LABs per month found at each marina LABM [n, m]. Lastly, an estimate of the pollutant load LOADLAB [n, m] from LABs at each marina is made with the BOD equation found at the beginning of this section.

A normalized seasonality curve for marinas, NORMLABM [*m*], was developed for LABs found at marinas. The normalized value for each month equals the total LAB for each month divided by the maximum number for the year, which occurred in January.

The maximum number of LABs per month is determined using the following algorithm:

$$MAXLAM [n, m] = MARINAWS [n] * OCCM [m] * LABPERM [m]$$

The occupancy rate OCCM [*m*] for a marina is 100 percent during the winter months of December through May, while in the summer it is 70 percent.

During the winter months, 28 percent of all boats found within a marina allowing LABs can be classified as LAB. The value LABPERM [*m*] increases only slightly to 33 percent during the summer months of June through November.

The number of LABs found at each marina per month is estimated as follows.

$$LABM [n, m] = MAXLAM [n, m] * NORMLABM [m]$$

The BOD equation is used for LABs at marinas to determine loading.

$$LOADLABM [n, m] = BOATPOPLAB * LOADRATELAB * CWTM [n] *$$
$$LABM [n, m]$$

Where: BOATPOPLAB = 1.8 persons per boat
LOADRATELAB = 0.76 kg BOD/person/day
CWTM [*n*] = Weighted pretreatment reduction coefficient for marinas

In order to determine CWTM [*n*], estimates on the types and quantities of the pretreatment facilities on board LABs must be made.

$$CWTM [n] = CDDLAB * MARINADD [n] + CHTLAB * MARINAHT [n] +$$
$$CMCLAB * MARINAMC [n] + CPOLAB * MARINAPO [n]$$

The input constants CDDLAB, CHTLAB, CMCLAB, and CPOLAB, were described in the previous section as being the reduction coefficient for each pretreatment methodology.

The input variables MARINADD [*n*], MARINAHT [*n*], MARINAMC [*n*], and MARINAPO [*n*] are estimates, in percentage, of each pretreatment methodology used by LABs at each anchorage.

3.7.6   Definition of Datasets

With the revised model formulation, the following representative datasets were needed to support the current model algorithms:

- Inventory of anchorages and marinas with live aboard characteristics;
- Monthly distribution of live aboard populations at anchorages and marinas;

- Monthly occupancy rates and live aboard component; and
- Onboard waste practices, treatment capacity and distribution among LABs.

The Antonini report presented data for the number of LABs at each anchorage over the course of a year. A normalized curve was developed for each of the three representative locations (Lower, Middle, Upper Keys) to estimate the number of LABs at an anchorage based on the maximum number of boats expected at the anchorage and its location in the Keys. Table 30 listed the three curves for the monthly distribution of LABs in the Lower, Middle, and Upper Keys. The number of boats can be adjusted for seasonality should new information on the maximum number of boats be developed. Table 34 identifies the appropriate curve to use based on the closest wastewater planning unit to the anchorage. The maximum number of LABs was assigned to each anchorage based on the data found in Antonini's report. Table 35 lists the maximum number of LABs expected for each anchorage. These are the default values in the CCAM, but can be changed by the user.

TABLE 34
ANCHORAGE LIVE ABOARD CURVE BY STUDY AREA

Wastewater Planning Unit/Island	Wastewater Planning Unit	Curve
Key West	0	1
Stock Island	1	1
Boca Chica	2	1
Bay Point	3	1
Lower Sugarloaf	4	1
Upper Sugarloaf	5	1
Cudjoe Key	6	1
Summerland Key	7	1
Big/Middle Torch Key	8	1
Ramrod Key	9	1
Little Torch Key	10	1
Big Pine Key	11	1
Bahia Honda Key	12	1
Marathon Primary	13	2
Marathon Secondary	14	2
Long Key/Layton	15	2
Lower Matecumbe	16	3
Upper Matecumbe	17	3
Windley Key	18	3
Plantation Key	19	3
Tavernier PAED 15	20	3
Rock Harbor PAED 16	21	3
PAED 17	22	3
PAED 18	23	3
PAED 19 and 20	24	3
PAED 22	25	3
PAED 21	26	3
Ocean Reef Club	27	3

TABLE 35
MAXIMUM EXPECTED NUMBER OF ANCHORAGE LIVE ABOARD BOATS

Anchorage	ID Number	Maximum Number of LABs
Christmas Tree Island	91	38
Garrison Bight	93	40
Houseboat Row	89	21
Cow Key Channel	90	50
Boca Chica Channel	92	25
Pine Channel	88	18
Boot Key Harbor	87	250
Key Colony Beach	86	9
Matecumbe Harbor	85	2
Islamorada	84	18
MM 84.5 Bayside	95	14
Community Harbor	83	14
Largo Sound	94	10
Cross Key	82	8
Card Sound Bridge	81	4

Shoreside LABs are handled in a similar fashion. The number of LABs is based on a percentage of the number of slips in a marina corrected for seasonality with an adjustment factor. Seasonal data for shoreside LABs were not based on geographic location. The Antonini report did not provide the level of detail for shoreside LABs as was given for anchorages. A single normalized curve was developed from the data presented previously in Table 28 to estimate the shoreside LABs. Table 36 presents the data used to compute the shoreside LAB numbers for each marina. Using the normalized curve, the monthly number of LABs at each marina can be determined based on the maximum number of LABs per marina. Table 37 contains a filtered list of the marinas from the master inventory list that allow LABs. In several instances, no data was available on the total number of slips available for boat dockage.

The Antonini report found that during the summer months, approximately 70 percent of the marina slips were occupied and one-third of them were LABs. This represents the maximum number of LABs for the months of June through November. The winter months assumed a 100 percent occupancy rate with 28 percent of these as LABs. Table 38 lists the occupancy rate and percent of occupied boats that are live aboards. These numbers represent the default values in the CCAM, but they can be changed by the user based on revised data or for scenario simulation.

TABLE 36
NORMALIZED DISTRIBUTION OF SHORESIDE LIVE ABOARD BOATS

Month	Seasonal Shoreside	Year-Round Shoreside	Total Shoreside
January	100.00%	97.67%	100.00%
February	84.09%	100.00%	93.02%
March	60.00%	94.88%	78.14%
April	36.36%	92.56%	64.88%
May	29.55%	97.67%	63.95%
June	27.27%	95.35%	61.63%
July	27.27%	95.35%	61.63%
August	20.45%	82.79%	51.86%
September	20.45%	82.79%	51.86%
October	46.36%	84.19%	65.81%
November	50.00%	83.26%	67.21%
December	81.82%	94.42%	89.07%

TABLE 37
MARINAS WITH LIVE ABOARDS

Marina	Live Aboards Allowed?	Number of Wet Slips
A&B Marina	Y	55
Blue Waters Marina	Y	
Boca Chica Naval Air Station – Marina	Y	20
Bonefish Marina & Condo Assoc.	Y	8
Boot Key Marina	Y	
Caloosa Cove Marina	Y	
Campbell's Marina	Y	110
Casa Cayo Condominium Association	Y	16
Chevron Docks	Y	6
Clipper Quality Seafood Inc.	Y	40
Cross Key Marina	Y	
Curtis Marine	Y	
Dockside Lounge and Sombrero Marina	Y	40
Dolphin Marina Assoc. Ltd.	Y	30
Dove Creek Marina (Snappers Restaurant)	Y	12
Faro Blanco Bayside	Y	70
Galleon Marina	Y	
Gilberts Motel and Marina	Y	35
Gulfstream Trailer Park and Marina	Y	30
Harbor Cay Club Condo Association	Y	24
Harborside Marina	Y	22
Hawks Cay Resort & Marina	Y	
Holiday Inn Resort	Y	15
Holiday Isle Marina	Y	
Hurricane Resort	Y	23
Islamorada Yacht Basin (Lorelei Resta)	Y	
Key Largo Harbour Marina	Y	
Key West Bight Marina	Y	
Key West Municipal Marina	Y	256

TABLE 37
(Continued)
MARINAS WITH LIVE ABOARDS

Marina	Live Aboards Allowed?	Number of Wet Slips
Key West Oceanside Marina	Y	
Key West Sea Port	Y	50
Key West Yacht Club	Y	66
Lagoon Resort and Marina	Y	11
Lands End Marina	Y	106
Manatee Bay Marina	Y	45
Marathon Seafood and Marina Inc.	Y	75
Marathon Yacht Club	Y	23
Marina Del Mar Bayside Resort	Y	2
Matecumbe Marina	Y	
Munro's Marina	Y	4
Murray Marine Sales & Svc Inc	Y	24
Ocean Reef Club	Y	150
Palm Bay Yacht Club	Y	15
Pelican Landing Resort and Marina	Y	15
Peninsular Marine Enterprises	Y	55
Pilot House Marina	Y	33
Plantation Yacht Harbor Resort	Y	
Point Laura Marina	Y	60
Reitmarine	Y	6
Safe Harbor Marina	Y	50
Sea Lobster Company	Y	50
Seacamp Association, Inc.	Y	40
Sombrero Resort & Lighthouse	Y	54
Steadman's Boat Yard	Y	4
Stock Island Public Ramp	Y	
Sundowner Restaurant/Senor Frijoles	Y	4
The Suites at Key Largo - Best Western	Y	
Winner Docks	Y	20

TABLE 38
MONTHLY OCCUPANCY RATES FOR SHORESIDE LIVE ABOARD BOATS

Month	Occupancy Rate	Percent of Live Aboard
January	100%	28%
February	100%	28%
March	100%	28%
April	100%	28%
May	100%	28%
June	70%	33%
July	70%	33%
August	70%	33%
September	70%	33%
October	70%	33%
November	70%	33%
December	100%	28%

Data on the number of LABs by pretreatment method was not identified and could not be developed from other sources. Table 39 lists the pretreatment values and the default distributions, both of which are applicable toward live-aboard vessels found at both marinas and anchorages. These numbers represent the default values in the CCAM, but the user can change these values based on revised data or for scenario simulation.

TABLE 39
LIVE ABOARD WASTE TREATMENT METHOD AND DISTRIBUTION

Onboard Waste Treatment Method	Boat Coefficient	Percent of LABs
Direct Discharge	1.00	100%
Holding Tank	0.50	0%
Macerator & Chlorination	0.30	0%
Shoreside Pump Out	0.00	0%

3.7.7 Integration Considerations

There are no significant integration considerations with the updated Component formulation.

3.8 Immediate Nearshore Waters Component

Comments and suggestions received during the DO 5 Technical Wrap-Up Workshop in January 2001 suggested the existence of a "Halo Zone" – the nearshore waters that are within 100 meters of the shore – around the more developed keys, which exhibited specific characteristics. However, an effort to better define the immediate nearshore waters in terms of water quality, ecological factors or other physical/chemical parameters concluded that there was no consensus or documentation on whether a halo zone actually exists, and if it does exist how it might be defined. Therefore, the term "halo zone" was abandoned. Instead, the study refers to the first 100 meters from shore as the "immediate nearshore waters."

The Immediate Nearshore Waters Component provides a defined transfer zone for introducing land-based stormwater and groundwater discharges into the immediate nearshore waters. This approach provides maximum flexibility for the CCAM. If the immediate nearshore waters are proven to exist by subsequent chemical, physical, or biological monitoring activities, then the Immediate Nearshore Waters Component will document the concentrated pollutant effects and can be retained. However, if the immediate nearshore waters are not proven, then the Immediate Nearshore Waters Component will only serve as an accumulator function prior to the transfer of land-based pollutants to the Marine Circulation Component.

Response of the immediate nearshore waters to the various pollutant sources with which it interacts- including stormwater runoff, groundwater discharges, wastewater effluent discharges, boating discharges, atmospheric loading and injection zone leakage-are handled by the Immediate Nearshore Waters Component. This component uses a GIS-based load and volume

accounting system developed for each of the modeled islands in the Florida Keys to provide the information required in the Marine Environment Module for estimation of the ambient water quality in the immediate nearshore waters.

3.8.1   Ancillary Investigation Activities

This phase of the investigation resulted in the review of pertinent literature. Literature sources for the Immediate Nearshore Waters Component are shown in the bibliography. Synopses are shown below:

- Tomasko and Lapointe (1991) studied the productivity and biomass of *Thalassia testudinum* (Turtle Grass) as related to water column nutrient availability and epiphyte levels. The study found that:

  - Soluble nutrient levels in nearshore waters of Big Pine Key were lower than those found in the canals directly receiving groundwater contaminated by OSDS.

  - Nutrient enrichment of near shore waters appears to have altered the structure of seagrass beds in the Florida Keys both inside and outside of canals, and that continued reliance of residents of the Florida Keys on OSDS's will further degrade affected meadows.

  - A previous study by Smith et al. (1981) stated that measurement of the limiting nutrient concentration is a poor indicator of eutrophication. A more useful indicator would be (water column) chlorophyll or some other particulate material.

- Lapointe et al. (1992) studied the nutrient availability to marine macroalgae in siliciclastic versus carbonate-rich coastal waters. The study suggested that while N removal would be more effective in temperate siliciclastic systems, P removal may be more effective in carbonate-rich tropical environments like the Florida Keys.

  - Abundant populations of frondose epilithic macroalgae from a variety of carbonate-rich tropical waters were significantly depleted in phosphorous relative to carbon and nitrogen when compared to macroalgae from temperate siliciclastic waters.

  - Seawater samples taken adjacent to benthic macroalgae from the carbonate-rich tropical waters contained relatively high levels Dissolved Inorganic Nitrogen (DIN) with low concentrations of Soluble Reactive Phosphorous (SRP), and showed elevated N:SRP ratios (mean = 36) compared to siliciclastic environments (mean <3).

  - Despite the significant differences in N:P availability between the coastal systems studied, a suite of natural and anthropogenic factors could rapidly shift N:P availability within any of these biogeochemical environments.

- Lapointe and Clark (1992) characterized watershed nutrient inputs, transformations, and effects along a land-sea gradient of four different ecosystems that occur with increasing distance from land. The study findings correlate with observations of increasing algal blooms, seagrass epiphytization and die-off, and loss of coral cover on patch and bank reef ecosystems, suggesting that nearshore waters of the Florida Keys have entered a stage of critical eutrophication.

  – In nearshore canal and seagrass meadows, human activities on land enrich groundwaters with ammonium and SRP, contributing to elevated concentrations of these nutrients.

  – The Nitrogen to Phosphorous ratios of sewage-enriched groundwaters are greater than 100:1 in the Keys due to selective adsorption of SRP onto calcium carbonate surfaces. SRP and ammonium concentrations decreased to low concentrations within approximately 1 to 3 kilometers from land, respectively.

  – With increasing distance from land, the kinetics of dissolved nutrient cycling by marine microbes and plants is very rapid, and dissolved organic pools, which are important to biological cycling, come to dominate the total nutrient pools. While nearshore canal systems and seagrass meadows tend to have elevated N:P ratios (typically greater than 15) and are primarily P-limited, more offshore patch and bank reefs have lower N:P ratios (6:1), suggesting a more N-limited oceanic influence. Finally, the study indicated that water clarity in the Keys is regulated by short-term meteorological events that increase turbidity and particulate nutrients, primarily in winter, and by increased nutrient loading during the rainy season that increases phytoplankton standing crops.

- Lapointe et al. (1993) conducted comparative studies that showed that chlorophyll a, turbidity, and total dissolved phosphorous were higher on bank reefs of the Florida Reef Tract (FRT) compared to similar reefs in less developed Caribbean regions. The study found that:

  – The threshold phosphorous concentrations for critical eutrophication in the shallow waters of the FRT are quite low (e.g. total dissolved phosphorous approximately 0.10 micromoles/1000cm^3 (μM)) and comparable to sensitive freshwater ecosystems.

  – Inputs of phosphorous, the primary nutrient element limiting algal growth and eutrophication in back-reef water of the FRT to coastal waters of the eastern Gulf of Mexico, appear to be carried downstream by prevailing currents toward the FRT.

- Lapointe et al. (1994) assessed relationships among nutrient concentrations of the water column and seagrasses along three onshore-offshore transects that occur with increase distance from shore. The study reported that seagrass communities in the Florida Keys are receiving increased nutrient loadings

from a variety of land-based human activities that are accelerating coastal eutrophication. The study stated that:

- Eutrophication in seagrass meadows in the Florida Keys and Florida Bay resulted in predawn hypoxia (typically less than 2.0 mg/l DO) or anoxia (typically less than 0.1 mg/l), especially during warm, rainy periods.

- Decreased oxygen levels resulted from both increased light-limitation, increased community respiration resulting from high macroalgal biomass, and increased sediment oxygen demand associated with mineralization of organic matter.

- Because dissolved inorganic nutrient concentrations were highly variable and did not include particulate or dissolved organic nutrient pools, the use of total N and P pools appeared to be the best single nutrient index of eutrophication as this measurement included all nutrient pools and was also a proxy for water transparency.

- Lapointe et al. (1996) studied the effects of stormwater nutrient discharges on eutrophication processes in nearshore waters of the Florida Keys. The study showed that:

  - Rainfall events are followed by periods of critically low dissolved oxygen in sensitive seagrass and coral reef communities in the Florida Keys.

  - Predawn dissolved oxygen at all stations dropped to hypoxic levels (2.5 mg/l) within days after the initial stormwater discharges in June 1992.

  - The impacts of reduced dissolved oxygen were most dramatic at an inshore station, where anoxia developed immediately following the first heavy rain event and persisted for several days.

  - Rainfall contains significant concentration of ammonium and nitrate, which enhance primary production in coastal waters adjacent to urbanized areas.

  - Rainfall in the Florida Keys during the study had an average DIN concentration of 15 μM, including approximately 6.2 μM of ammonium. Low to undetectable concentrations of TP and SRP were present in the rainfall, pointing to the importance of wastewater sources of phosphorous.

  - Nutrient enrichment increases water-column light attenuation due to increased phytoplankton biomass, suspended materials, and dissolved organic matter, resulting in light limitation of phytoplankton growth and reduced oxygen concentrations.

  - Over time, increased sediment oxygen demand (SOD) resulting from the bacterial mineralization of accumulated organic matter leads to

cumulative reduction of dissolved oxygen and hyper-eutrophication in wastewater-impacted waters.

- The results showed that concentrations of nutrients and chlorophyll a in the Study Area were above critical threshold levels known to mark the decline of coral reefs; dissolved oxygen concentrations also fell below the State of Florida's minimum standards (4.0 mg/l) for marine water quality at all stations.

- Rudnick et al. (1999) explored how changing freshwater inflow to the southern Everglades is likely to change the input of nutrients to Florida Bay. The study found that based on a nutrient budget of Florida Bay, both N and P inputs from the Gulf of Mexico greatly exceed inputs from the Everglades, as well as inputs from the atmosphere and the Florida Keys. In a previous study Hendry et al. (1981) reported bulk N and P deposition on Bahia Honda Key, near Key West, in biweekly samples in 1978 and 1979.

  - They reported TN deposition of 0.32-g N m^{-2} yr^{-1} and TP deposition of 0.017-g P m^{-2} yr^{-1}.

  - The study estimated that the freshwater Everglades contribute < 3 percent of all P inputs and < 12 percent of all N inputs to the bay.

3.8.2   Resulting Data

Below is a summary of data that is pertinent in developing the Immediate Nearshore Waters Component.

- In the carbonate rich area of the Florida Keys, the ratio of DIN:SRP is relatively high at 36 when compared with siliciclastic environments with DIN:SRP ratios typically less than 3.

- The N:P ratios of sewage-enriched groundwaters are generally greater than 100:1 in the Keys due to selective adsorption of SRP onto calcium carbonate surfaces.

- Nearshore canal systems and seagrass meadows tend to have elevated N:P ratios (generally greater than 15) and are primarily P-limited; more offshore patch and bank reefs have lower N:P ratios (6:1), suggesting a more N-limited oceanic influence.

- Eutrophication in seagrass meadows in the Florida Keys and Florida Bay resulted in predawn hypoxia (typically less than 2.0 mg/l dissolved oxygen) or anoxia (<0.1 mg/l), especially during warm, rainy periods.

- Rainfall events are followed by periods of critically low dissolved oxygen in sensitive seagrass and coral reef communities in the Florida Keys.

- Predawn DO at all stations dropped to hypoxic levels (typically less than 2.5 mg/l) within days after the initial stormwater discharges in June, 1992.

- Rainfall in the Florida Keys had an average wetfall DIN concentration of 15 µM (0.105 mg/l). Low to undetectable concentrations of TP were present in the rainfall.

- Dryfall TN deposition rate is 0.32-g N m^{-2} yr^{-1} and TP deposition rate is 0.017-g P m^{-2} yr^{-1}.

- Freshwater from the Everglades contributes generally less than 3 percent of all P inputs and generally less than 12 percent of all N inputs to the Florida Bay.

3.8.3   Revised Component Formulation

The original formulation of the Integrated Water Module envisioned the definition of one or more specific cells, defined by fixed-distance offsets from the shoreline, which would be used to evaluate water quality characteristics at the immediate interface with the shoreline. Subsequent discussions indicated that the gross size of these elements would tend to mask localized impacts caused by canals, concentrations of septic tanks, and any pseudo-point source discharges.

The evolution of the analytical approach being used for the Marine Environment Module, subsequent to the DO 5 Technical Wrap-Up Workshop, resulted in the development of a mesh of 30- x 30-foot elements that are used in the GIS-based dispersion modeling of the pollutants generated by the islands and discharged at the shoreline. This approach provides a much better basis for estimation of pollutant concentrations in the immediate nearshore waters and has been adopted in lieu of the approach envisioned in the original formulation of the Integrated Water Module.

The model formulation presented in DO 5 has not been reformulated, but the concepts and model algorithm have been further refined. The Immediate Nearshore Waters Component will receive loads from the Stormwater, Groundwater, Disposal Well, Boat, and Weather Components. Volumetric and water quality changes in the immediate nearshore waters will be simulated in the Marine Environment Module using a GIS-based system with a grid of cells with a constant grid element size of 30 x 30 feet. Each modeled island will be divided into drainage basins as previously described in the Stormwater Component. The model therefore needs to represent runoff of water and pollutants from each island to the immediate nearshore waters. This will be accomplished by calculating the linear footage of the shoreline for each drainage basin (point of contact between the drainage basin and the immediate nearshore waters), and applying the loads to each cell on a per foot basis as follows:

- Input Loads, for each watershed, consisting of water volume and pollutant load will be received from the Stormwater, Groundwater, Disposal Well, Boat, and Weather Components.

- Shoreline Flux Rates will be calculated from the volumes and loads and the length of the shoreline for each watershed.

- Output to the Marine Module will consist of shoreline flux rates for each watershed.

3.8.4 Enabling Assumptions

- Pollutants are conservative and transfer without any loss to volatilization or settling.

- Pollutants accumulated in a watershed/wasteshed are dispersed at a uniform flux rate across the shoreline interface to the immediate nearshore water elements.

- The immediate nearshore waters is not precisely defined for the Keys and may be determined by documented seagrass recession (anecdotally in the range of 70 to 100 feet in width), water quality gradients or some combination of the two. Consequently, the use of a GIS-based methodology to disperse and transport pollutants, as demonstrated at the DO 5 Wrap-Up Workshop by Dr. Mark Brown, eliminates the need to develop a system of small grid elements within the immediate nearshore water as part of the Integrated Water Module.

- Nutrient upwelling from shallow effluent disposal wells is idealized as occurring within the immediate proximity of the shoreline due to the lack of documented aquacludes and aquatards in the surficial geology underlying the Keys. The Groundwater Module accumulates all nutrient upwelling occurring within a delineated wasteshed, divides the cumulative return flux by the shoreline length for the wasteshed, and then transfers the resulting flux rate to the Marine Module where it is treated as a uniform loading rate for each foot of interface between the Marine Module's grid and the wasteshed's shoreline.

- Deep effluent disposal wells (2,000+ feet) have been idealized as "black holes" to the extent that none of the effluent discharged to a deep well ever reaches the immediate nearshore waters. The Groundwater Module eliminates any return nutrient flux for deep disposal wells.

- Offshore upwelling of nutrients is eliminated pursuant to the conceptual construct for the deep effluent disposal wells.

3.8.5 Current Computational Algorithm

The algorithm was developed for computing the following:

- Net initial input volume, and

- Net initial pollutant input load.

Response of the immediate nearshore waters to the various pollutant sources - including stormwater runoff, groundwater discharges, disposal well discharges, boating discharges, and atmospheric loading - are handled by the Immediate Nearshore Waters Component.

The pollutant loading algorithm for the Stormwater Component is as follows:

$$CELLSWLOAD_{[i,d]} = SWM_{[b]} / L_{[b]} * CL_{[i]}$$

Where: $CELLSWLOAD_{[i,d]}$ is the mass of pollutant entering cell (i) in each day (d) in pounds per day.
SWM$_{[b]}$ is the surface water pollutant mass from each drainage basin (b) in pounds per day as calculated by the Stormwater Component.
$L_{[b]}$ is the length of the shoreline in feet.
$CL_{[i]}$ is the length of the cell (i) in feet (30 feet).

The water flow for the Stormwater Component is as follows:

$$CELLSWQ_{[i,d]} = SWQ_{[b]} / L_{[b]} * CL_{[i]}$$

Where: $CELLSWQ_{[i,d]}$ is the water entering the cell i on a specified day (d) (gpd).
$SWQ_{[b]}$ is the surface water flow from each drainage basin, b (gpd) as calculated by the Stormwater Component.
$L_{[b]}$ is the length of the shoreline for each basin (b) in units of feet.
$CL_{[i]}$ is the length of the cell (i) (30 feet).

The groundwater and deep well contribution will be handled with a similar formulation. The pollutant algorithm for the Groundwater Component is:

$$CELLGWLOAD_{[i]} = GWM_{[b]} / L_{[b]} * CL_{[i]}$$

Where: $CELLGWLOAD_{[i]}$ is the mass of pollutant entering the cell (i) in units of pounds per day.
$GWM_{[b]}$ is the groundwater water pollutant mass from each drainage basin (b) in units of pounds per day as calculated by the Groundwater Component.
$L_{[b]}$ is the length of the shoreline (b) in units of feet.
$CL_{[i]}$ is the length of the cell (i) (30 feet).

The water flow for the Groundwater Component is as follows:

$$CELLGWQ_{[i]} = GWQ_{[b]} / L_{[i]} * CL_{[i]}$$

Where: $CELLGWQ_{[i]}$ is the water entering the cell (i) in gpd.
$GWQ_{[b]}$ is the groundwater flow from each drainage basin (b) in units of gpd as calculated by the Groundwater Component.
$L_{[b]}$ is the length of the shoreline (b) in units of feet.
$CL_{[i]}$ is the length of the cell (i) (30 feet).

The pollutant algorithm for the Disposal Well Component is:

$$CELLDWLOAD_{[i]} = DWM_{[b]} / L_{[b]} * CL_{[i]}$$

Where: $CELLDWLOAD_{[i]}$ is the mass of pollutant entering the cell (i) in units of pounds per day.
$DWM_{[b]}$ is the deep well water pollutant mass from each drainage basin (b) in units of pounds per day as calculated by the Disposal Well Component.
$L_{[b]}$ is the length of the shoreline (b) in unit feet.
$CL_{[i]}$ is the length of the cell (i) (30 feet).

The water flow for the Disposal Well Component is as follows:

$$CELLDWQ_{[i]} = DWQ_{[b]} / L_{[b]} * CL_{[i]}$$

Where: $CELLDWQ_{[i]}$ is the water entering the cell (i) in units of gpd.
$DWQ_{[b]}$ is the disposal well flow from each drainage basin (b) in units of gallons per day as calculated by the Disposal Well Component.
$L_{[b]}$ is the length of the shoreline in units of feet.
$CL_{[i]}$ is the length of the cell (i) (30 feet).

The pollutant algorithm for the Boating Component is as follows:

$$CELLBOWLOAD_{[i,d]} = BO_{[i]} * BON_{[i]}$$

Where: $CELLBOWLOAD_{[i,d]}$ is the mass of pollutant entering cell (i) in each day (d) in pounds per day.
$BO_{[n]}$ is the surface water pollutant mass from each boat (n) in pounds per day as calculated by the Boating Component.
$BON_{[i]}$ is the number of boats in each cell (i).

The water flow for the Boating Component is as follows:

$$CELLBOQ_{[i,d]} = BOQ_{[i]} * BON_{[i]}$$

Where: $CELLBOQ_{[i,d]}$ is the water entering the cell (i) in each day in units of gpd.
$BOQ_{[i]}$ is the surface water flow from each boat (n) (gpd) as calculated by the Boating Discharge Component.
$BON_{[i]}$ is the number of boats in each cell (i).

The Wetfall and Dryfall Components will be assumed to be distributed at a uniform rate to each cell within the model domain. Based on rainfall volume, the wetfall concentration will be converted to units of mass per unit area per unit of time to be consistent with the units of dryfall. These mass loads will be added to the masses within each cell and will be superimposed on the mass loads originating from the drainage basins. The wetfall and dryfall equations are the same used for the Circulation Component.

3.8.6 Definition of Datasets

No specific datasets are required for this component.

3.8.7 Integration Considerations

The Immediate Nearshore Waters Component must integrate with and receive loads from the stormwater (non-point source), Groundwater, Disposal Well Components. NPSLAM, GWPTAM, and DWIZM will be integrated via the linkages with the wastesheds and grid cells of the immediate nearshore waters. An overlay of the immediate nearshore waters grid on the watersheds developed in the NPSLAM Component will be used to determine the linkages between specific wastesheds and specific immediate nearshore waters grid cells. Cells will be 30 x 30 feet. Bathymetric data will be used to define depths, and cell volumes will be calculated as surface area multiplied by depth.

3.9 Circulation Characteristics Component

Circulation patterns within the marine waters of the Study Area have a direct and significant impact on the concentrations and residence times in the immediate nearshore waters. The Circulation Component produces information regarding circulation characteristics and water quality loadings within the Study Area, which is required by the Marine Module. Actual movement of water volumes and pollutant loads within the marine waters is handled as elements of the Marine Module.

The Marine Module was ultimately removed from the model due to insufficient data (see DO 11 Report).

3.9.1 Ancillary Investigation Activities

The DO 5 Wrap-Up Workshop provided information and insights into the importance of circulation within the Florida Keys, but also raised numerous questions and concerns regarding the method in which the CCAM would address the issues of circulation and marine water quality within the FKCCS Study Area. Based upon this input, the investigative efforts for this component focused on answering the following logical sequence of questions:

- Do circulation models exist that cover the Study Area?
- If they exist, are they suitable for the purposes of the CCAM?
- If they are suitable, can they be incorporated into the CCAM given schedule and budgetary constraints?

Each of these questions is discussed in detail in the following subsections.

Identification of Existing Models

Given the size and complexity of the circulation within the Study Area, the importance of understanding water movements from Florida Bay through the Keys into the Florida Straits, and the input received during the DO 5 Technical Wrap-Up Meeting, the Contractor reached the following four conclusions with respect to how to undertake the investigation of possible models:

- Development of a custom model of the Study Area "from scratch" with new model code, with a sufficiently fine grid/mesh to represent flows between the islands, could not be done within the allocated schedule window of the Test Model and would be cost prohibitive.

- Development of a study specific model of the Study Area "from scratch" using an existing model code, with a sufficiently fine grid/mesh to represent flows between the islands, could not be done within the allocated schedule window of the Test Model and would be cost prohibitive.

- Development of a study specific model of the Study Area "from scratch" using an existing model code, with a relative coarse grid/mesh to represent flows between the islands, could not be done within the allocated schedule window of the Test Model and would be cost prohibitive.

- Adaptation of an existing model that included the FKCCS Study Area, with a sufficiently fine grid/mesh to represent flows between the islands, could potentially be done within the allocated window of the Test Model and may well be within the existing FKCCS budget.

It is this last conclusion, adaptation of an existing model, which provided the focus for the investigation of possible models to be used within the Circulation Component.

The first step in this effort was to contact recognized professionals who have been centrally involved with the investigation and modeling of circulation and water quality within the Florida Keys. To this end, the following individuals were contacted with respect to existing models:

- Dr. Thomas Lee, from the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS), suggested that the review of models that were used in the Study Area should include models such as:
  - RMA-10 (Rob McAdory at Waterways Experiment Station (WES)).
  - EWHM (Zakie Moustafa at SFWMD).
  - MICOM & HYCOM (Eric Chassignet at University of Miami RSMAS).
  - POM (Frank Aikman at NOAA).
  - FATHOM (Bill Nuttle).

- John Wang, from the University of Miami's RSMAS, developed a hydrodynamic model for Biscayne Bay and an area to the east of the keys. Dr. Wang was contacted to try and obtain a copy of his report and he indicated:

  - No report had been prepared describing the Biscayne Bay Model.

  - He has the only written document, an abstract, that describes two models; one of Biscayne Bay (BB Model); the other of the Southeast Florida Shelf (SEFS Model) which extends 60 km seaward from the Florida Keys and stretches from Palm Beach to Key West.

  - The modeled area did not include the area north of the keys and is therefore inadequate for the FKCCS, which requires a study domain that encompasses the Keys, and also extends north and south of the Keys.

- Dr. Rob McAdory, Chief of WES's Tidal Hydraulics Branch, developed the RMA-10 hydrodynamic model that is used in WES's Florida Bay Model regarding the possible adaptation of RMA-10 for the CCAM. Dr. McAdory indicated:

  - RMA-10 was being used in a two-dimensional mode for the Florida Bay Model.

  - The model grid for the Florida Bay model did not cover the western extent of the FKCCS Study Area.

  - It would be possible to "cut out" a portion of the Florida Bay model that covers the majority of the eastern portion of the Study Area, in order to reduce the model domain, and extend the model to cover Key West.

- Dr. Frank Aikman, with the NOAA, has applied the Princeton Ocean Model (POM) primarily to provide boundary conditions for the RMA-10 Circulation Component of the Florida Bay model.

  - In the vicinity of the Keys the model mesh is 5 km.

  - The model includes Wind and Tide Components, but no freshwater inflows.

  - He is not currently supporting the model and does not consider it appropriate to provide circulation vectors for the Keys.

  - Dr. Aikman said that various versions of POM had also been applied in the region by Christopher Mooers of RSMAS, and Richard Patchen and James Herring of DYNALYSIS of Princeton.

- Dr. Mark Dortch, Chief of the Water Quality and Contaminant Modeling Branch of USACE's WES, is responsible for the development of the CE-QUAL–ICM model's Water Quality Simulation Components for the Florida Bay model. When consulted about a possible approach for adapting the Florida Bay model for the Water Quality Components of CCAM, Dr. Dortch also indicated that he believed that it would be possible to:

    – Extract a section of the WES model that covers the majority of the eastern portion of the Study Area in order to reduce the model domain.

    – Add a new area to the model to cover the area to Key West, which is not in the WES model.

    – Dr. Dortch also believed that the ADCIRC model might also be useful for the FKCCS and suggested that Dr. Norman Scheffner should be contacted.

- Dr. Norman Scheffner, from WES's Coastal and Hydraulics Laboratory, has conducted hydrodynamic modeling of the region using the ADCIRC model. In response to a query on the potential use of ADCIRC for modeling "normal" weather conditions in the Study Areas, rather than hurricane conditions, Dr. Scheffner indicated:

    – Report No. 3, *Development of a Tidal Constituent Database for the Western North Atlantic and Gulf of Mexico*, would provide a basis for circulation modeling

    – The model mesh was, however, coarse in the vicinity of the Keys (5 km) and would need to be refined.

    – Dr. Scheffner transferred electronic files with ADCIRC results and the model mesh, and he also indicated that he was willing to assist us by refining the model, if required.

- Dr. Zakie Moustafa, with SFWMD, is currently conducting circulation modeling with the Everglades Wetland Hydrology Model (EWHM), which is a modification of the Environmental Fluid Dynamic Code (EFDC).

    – EWHM is being used to simulate the circulation in Florida Bay to an area just southeast of the Keys.

    – The model is a two-layer curvilinear model with 2,165 active cells in each layer.

    – Cell lengths range from less than 200 meters in the vicinity of the Florida Keys to as large as 4 km in other areas.

    – Freshwater inflows from mainland Florida and wind are included in EWHM.

    – Completion of model development is expected in approximately one year.

- Dr. Moustafa also indicated that there was expert review of the FATHOM and RMA-10 models that was conducted by the Florida Bay Physical Science Team.

- Dr. Eric Chassignet, of the University of Miami's RSMAS, has modeled circulation in the Florida Keys with the Miami Isopycnic Coordinate Ocean Model (MICOM).

  - MICOM is a large scale model for the North Atlantic that includes the Keys.

  - Boundaries are set at North and South America to the west, and Africa to the east.

  - Mesh size in the finite element model is approximately 7 km in the vicinity of the Keys.

  - MICOM is not suitable for detailed simulation of the shallow waters found in the Study Area.

  - Dr. Chassignet is currently developing the Hybrid Coordinate Ocean Model (HYCOM), which extends the geographic range of applicability of MICOM model towards shallow coastal seas.

The second step was to investigate other models that could possibly be developed or adapted to support the CCAM. Internet research indicated the following possibilities:

- *FATHOM* – A box model that was developed to simulate spatial variation of salinity in Florida Bay for the period 1965 through 1995, based on hydrologic inputs. Several reviewers believed that the model approach could serve as a useful tool to examine the long-term changes (greater than monthly) in Florida Bay salinity and mass (water) balance. At the time of the review (September 1999), however, the reviewers felt that the model was insufficiently calibrated and was not ready for its intended use of examining salinity changes arising from selection of different management alternatives.

- *Princeton Ocean Model* – Christopher Mooers and Rennelly Perez of RSMAS, and James Herring and Richard Patchen of DYNALSYS, have used Princeton Ocean Model to conduct large-scale modeling in the Gulf of Mexico.

The third step in the investigation process was to identify, acquire and review copies of relevant reports related to modeling of circulation and water quality in the Study Area. Each of the reports that were obtained and reviewed are described in the following paragraphs:

- Meeting Notes for FKCCS Water Circulation/Water Quality Workshop (October 13-14, 1999) – this document contains the final meeting notes for the technical workshop held to discuss the water circulation and water quality model framework for the FKCCS. Some data and the study objectives were

presented, and the opinions of experts solicited, including the following conclusions:

- A year-long simulation would take approximately three weeks to run given a resolution of 12,000 elements.

- A 200,000-element model (50 x 50 meters) would take approximately one year to run.

- Anything less than a 400 x 400 meter grid size would be extending the limits in terms of computational time.

- It is not feasible to model the near field for an area as large as the Florida Keys, where the domain of interest extends about 150 km long and about 10 km on both sides.

- The only way to model the near-field is to model specific points of interest and/or to use section models to study points of interest.

- *ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries, Report 5, A Tropical Storm Database for the East and Gulf of Mexico Coasts of the United States* – this report summarizes results of a numerical storm surge study conducted for the eastern United States seaboard and Gulf of Mexico coastline:

  - The ADCIRC-2DDI hydrodynamic model was used.

  - Although the Florida Keys were included in the model, the model is for infrequent events (hurricanes), and is not applicable to the FKCC study in which normal seasonal events are required.

- *ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries, Report 3, Development of a Tidal Constituent Database for the Western North Atlantic and Gulf of Mexico* - this report summarizes the results of the application of the ADCIRC for normal conditions of varying tides (non-hurricane circulation conditions):

  - The model was developed for an extensive domain that included the western north Atlantic, Gulf of Mexico, Caribbean Sea, and includes the entire Florida Keys.

  - The model was run in a two-dimensional mode, with relatively coarse variable finite element sizes that averaged approximately 5 km in length.

  - This model can be modified by reducing the mesh size to simulate details in the Keys and immediate vicinity.

Assessment of Suitability

For an existing model to be classified as being suitable for incorporation into the CCAM, it must meet the following criteria:

- Cover the entire FKCCS Study Area, or have been successfully applied under conditions representative of the Florida Keys.

- Have received sufficient peer review that it can reasonably be described as "accepted" with the community of circulation modelers.

- Documented with report, calibration/validation results, and model code.

- Be in the public domain (non-proprietary).

- Accurately simulate 2-dimensional current patterns that reasonably correlate with field observed flow patterns.

- Accurately simulate pollutant transport processes and reasonably duplicate observed water quality field data.

Table 40 summarizes the suitability of the completed and documented models that were identified through the foregoing investigations. As can be seen, there are only six models under consideration, all of which are large-scale models with coarse model mesh in the vicinity of the Keys.

TABLE 40
SUITABILITY OF MODELS

Criteria	Developed Regional Models			Model Codes		
	Florida Bay Model	ADCIRC	MICOM	Princeton Ocean Model	RMA-2 with RMA-4	RMA -10
Covers the entire FKCCS Study Area	No	Yes	Yes	Yes	Could	Could
Model accepted by peer review	No	Yes	Yes	Yes	Yes	Yes
Public domain model	Yes	Yes	Yes	Yes	Yes	Yes
Simulates observed flow patterns	Yes	Yes	Yes	Yes	Could	Yes
Simulates water quality conditions	Yes	No	Yes	No	Yes	No

Likelihood of Successful Incorporation

Existing models have been developed using different philosophies as well as a variety of programming languages, enabling assumptions, and programming strategies. For a model to be successfully incorporated in the CCAM, it must generally satisfy the following requirements:

- Compatible with the CCAM framework.

- Compatible with the CCAM coding and scripts.

- Able to run in the same operating environment as the CCAM.

- Capable of executing iterative simulations required by the CCAM in a reasonable computational period.

- Capable of being adapted within the CCAM framework and within the FKCCS schedule.

- Capable of being implemented within the existing budgetary constraints.

It does not appear that any of the candidate regional models or model codes, operating as stand-alone models or callable subroutines, are likely to be successfully adapted due to their run-times, the complexity of developing and testing suitable interfaces with the GIS-based architecture of the CCAM, and the constraints placed on the adaptation process by the current FKCCS schedule and budget constraints.

Model Adaptation Conclusions

The following observations and conclusions have been reached based upon the ancillary investigations that have been undertaken to support the Circulation Component:

- A state-of-the-art 3-D circulation model could not be developed for the Florida Keys due to the constraints on computer computational power, simulation run times, and constraints placed on the available schedule and budget.

- An approach needs to be developed that reduces/eliminates the numerical processing requirements and the model run times for the simulated events given existing schedule and budget constraints.

- Net circulation vectors could reasonably be developed based upon the output from existing circulation models that have full coverage of the FKCCS Study Area.

- The model mesh from the existing circulation model selected to provide net circulation vectors could also be used as the basis for calculating pollutant loading associated with wetfall and dryfall deposition.

- The current version of ADCIRC could be used to provide net circulation vectors for the FKCCS Study Area as an alternate approach to iterative modeling within the CCAM and satisfying model development/adaptation cost and timing constraints.

The ADCIRC model mesh was developed at a fairly large scale relative to the level of detail desired in the CCAM and the simplification of land masses in the mesh eliminates tidal flows between Florida Bay and the Florida Straits in most of the channels between the islands.

3.9.2 Resulting Data

The ancillary investigation resulted in providing data on:

- ADCIRC GIS coverage,
- Mean depth values for ADCIRC Mesh,
- ADCIRC Output Files,
- FORTRAN "extractor" program for ADCIRC vectors, and
- ADCIRC Mesh Net Circulation Vectors GIS coverage.

ADCIRC Mesh GIS Coverage

The ADCIRC mesh provided by USACE was imported into GIS. The GIS will be used to calculate the centroid of each ADCIRC mesh for use in calculating net circulation vectors.

Mean Depth Values for ADCIRC Mesh

The input file "eastcoast_95_II.grd" provided by the USACE contained data on the elevation of the bed at each node (apex of triangles). The file also contains information on the location (latitude and longitude) of each node.

ADCIRC Output Files

The output file "ec_95d.tdb" provided by the USACE contained simulations of velocity vectors and tidal elevation at each node.

FORTRAN "Extractor" Program for ADCIRC Vectors

The FORTRAN program "ec_95d_tide2.f" provided by the USACE was developed for extracting information from the ADCIRC output file "ec_95d.tdb." The program prompts for the start date, simulation length, simulation time interval, latitude and longitude, and provides velocity magnitude and direction, and tidal elevation.

ADCIRC Mesh Net Circulation Vectors GIS Coverage

The net circulation vectors for the GIS will be based on circulation vectors provided by ADCIRC. The centroid of each element will be used in calculating net circulation vectors.

3.9.3 Revised Component Formulation

The component formulation originally included in DO 5 has been further refined for developing the net vectors resulting from hydrodynamic circulation for the Florida Keys. With the insights gained from the ancillary investigations, and the input from the DO 5 Technical Wrap-Up Workshop, the following refinements have been made to the initial formulation:

Net Circulation Vectors

CCAM will use net circulation vectors, comprised of both current velocity and flow direction, as developed by USACE in the ADCIRC model (*Report 3, Development of a Tidal Constituent Database for the Western North Atlantic and Gulf of Mexico*) for normal tidal conditions. Specific refinements include:

- Clipping the elements of the triangular irregular mesh of the ADCIRC model that are either completely or partially contained within the FKCCS Study Area.

- Modification and use of the FORTRAN program developed by USACE to extract geo-spatially explicit vector information from the triangular irregular mesh used in the ADCIRC modeling results provided by the Waterways Experiment Station.

- Extract circulation vectors for one average steady-state neap and one average steady-state spring tide.

- Supplement and/or replace, as necessary, ADCIRC vectors with field-data obtained from Harbor Branch Oceanic Institute.

- Development of a GIS utility to translate the net circulation vectors developed for the triangular irregular mesh in the ADCIRC elements, to the smaller rectilinear raster-based elements utilized in the Marine Module.

Given the capabilities of the current ADCIRC model and USACE's decisions to use the model on an "as is" basis due to budget constraints, tidal flows between Florida Bay and the Florida Straits that occur in channels between most of the islands will be excluded, and the net circulation vectors will not consider the effects from rainfall, freshwater inflows from significant on-shore streams, or wind on circulation patterns in the FKCCS Study Area.

Discussions with the Government Study Team and their local experts, during a meeting on July 9, 2001 to discuss the circulation issues of the Marine Module, highlighted a concern that the broad field net transport vectors derived from the ADCIRC model might not correlate with point vectors that have been measured by local investigators. Discussion of one specific case – circulation in the vicinity of the Seven-Mile Bridge – highlights the nature of the data limitation and differences in procedure:

- The broadfield net transport vector generated from the ADCIRC output for the triangular element covering the entire bridge reach showed a net southerly vector with a low velocity.

- The point velocity measure in the boat channel at the southern end of the bridge also showed a generally southern net velocity, but at a different vector bearing and at a higher flow velocity.

- Unfortunately, no point velocity measurements were made at different areas of the bridge that could be analyzed in conjunction with the boat channel point velocity measurement, to estimate an equivalent broad field net vector, which could be compared to the broadfield vector developed from the ADCIRC model output.

An additional problem with the ADCIRC model in its current form is that all of the Keys are idealized as three islands (Key West/Big Pine, Marathon, and Key Largo) with no allowance for any flows through the inter-island channels. Consequently, flows in the areas immediately adjacent to the idealized three islands are shunted from their normal flow paths around the three islands.

Recognizing these problems, the Government Study Team directed the Contractor to develop a solution to provide flow through the existing channel cuts. The procedure that was developed included the following allowances:

- Net transport vectors in the outer elements of the ADCIRC model grid were retained in the current form.
- Major channels with point velocity measurements were identified.
- Net flows in the ADCIRC mesh elements immediately adjacent to the three idealized islands were rerouted through the identified major channels, with adjustments to maintain volumetric continuity, thereby eliminating the ADCIRC model's shunting of flows and minimizing the actual flow paths between the individual islands.

These revised flows are provided to the Marine Module and serve as the basis for the net flow vectors used in its 30 x 30-foot model grid.

Atmospheric Loading

CCAM will generate daily pollutant loading values for wetfall and dryfall for each of the Marine Module's raster mesh cells for use in assessing ambient marine water quality conditions in the Marine Module. Specific refinements include:

- Clipping the elements triangular irregular mesh of the Marine Module's raster mesh cells.
- Modification and use of the FORTRAN program developed by USACE to extract geo-spatially explicit vector information from the triangular irregular mesh used in the ADCIRC modeling results provided by the WES.
- Development of a GIS utility to translate the net circulation vectors developed for the triangular irregular mesh in the ADCIRC elements, to the smaller rectilinear raster-based elements utilized in the Marine Module.

These revisions in the formulation of the Circulation Component will provide the tidal driving forces and pollutant loadings required for the raster based modeling system being used in the Marine Module.

3.9.4 Enabling Assumptions

The following assumptions are used in the Circulation Component to enable programming:

- Water movement within those portions of the Florida Keys, Florida Bay and the Florida Straights that lie within the FKCCS Study Area is explicitly modeled in the Marine Module.

- The Circulation Component will provide net circulation vectors, each comprised of flow velocity and direction, to the Marine Module.

- The use of the coarse mesh ADCIRC model is acceptable, although it is not expected to provide the optimal level of detail.

- Net circulation vectors will be developed for normal tidal conditions.

- Net circulation vectors will not be developed for either episodic or extreme events (hurricanes or tropical disturbances) as they are not representative of normal weather conditions in the Florida Keys.

- Pollutants will be treated as conservative, non-reactive neutrally buoyant materials that are uniformly dispersed within any model element, that do not volatilize or settle.

- Modeling of the component species dynamics of TN and TP are not envisioned within the CCAM given the unavailability of a consistent set of nutrient species data for the separate components of the Integrated Water Module that discharge to the Immediate Nearshore Waters Component and thence to the Circulation Component.

- Nutrient cycling between the water column, biomass and the benthos will not be considered within this component.

3.9.5 Current Computational Algorithm

The computational algorithm for the Circulation Component has three distinct elements that are described in the following paragraphs.

Net Circulation Vectors

Net circulation vectors within the FKCCS Study Area will be developed from the ADCIRC model output provided by WES. No algorithm is required of the CCAM since the computation of circulation patterns has previously been executed by USACE. Extraction of the net vectors for the triangular irregular model mesh will be accomplished using the FORTRAN program that accompanied the model output files.

Dryfall Pollutant Loadings

Dryfall loading for a specific element of the triangular irregular ADCIRC model mesh will be calculated using the following equation:

$$DRYLOAD\ [y, d] = DRYFALL\ [y, d] * CELLAREA\ [x]$$

Where: DRYLOAD [x, y, d]   is the calculated daily load in specific mesh element [x] of pollutant [y] due to dryfall, for a specific day [d] (in pounds).

                DRYFALL [y, d]   is the rate of dryfall for a specified pollutant [y] for a specific day [d] (pounds per square foot per day).

                CELLAREA [x]   is the area of the element of the Marine Module's raster mesh cells [x] (square feet).

Wetfall Pollutant Loadings

Wetfall loading for a specific element of the triangular irregular ADCIRC model mesh will be calculated using the following equation:

$$WETLOAD\ [y, d] = WETFALL\ [y, d] * RAIN * CELLAREA\ [x] * 5.19*10^{-6}$$

Where: WETLOAD [x, y, d]   is the calculated daily load in specific mesh element [x] of pollutant [y] due to wetfall, for a specific day [d] (pounds).

                WETFALL [y, d]   is the wetfall concentration for a specified pollutant [y] for a specific day [d] (mg/l).

                RAIN[d]   is the rainfall for a specific day [d] (inches per day)

                CELLAREA [x]   is the area of the Marine Module's raster mesh cells [x] (square feet).

                                        $5.19*10^{-6}$ is a unit conversion.

Rainfall Volume

Rainfall volume input to a specific element of the triangular irregular ADCIRC model mesh will be calculated using the following equation:

$$RAINVOL\ [x, d] = RAIN\ [d] * CELLAREA\ [x] / 12$$

Where: RAINVOL [x, d]   is the volume of rainfall entering a specific mesh element [x] for a particular day [d] (cubic feet).

                RAIN [d]   is the daily rainfall depth for a particular day [d] (inches).

                CELLAREA [x]   is the area of the Marine Module's raster mesh cells [x] square feet.

                                          12 is a unit conversion from inches to feet.

3.9.6   Definition of Datasets

This component uses a customized load and volume accounting system developed for each of the triangular irregular ADCIRC model mesh elements in the FKCCS Study Area to provide net circulation vectors and pollutant loadings throughout the marine waters. The two datasets developed within this component's work efforts include:

Circulation Elements from the ADCIRC Model Triangular Irregular Mesh

The circulation element will be represented by the centroid of each ADCIRC element. The dataset will be developed in GIS.

Net Circulation Vectors from the ADCIRC Model Output

Velocity vectors from the ADCIRC model are included in an electronic file provided by USACE. The vectors will be extracted for the centroid of each ADCIRC element for use in the Marine Module within GIS.

3.9.7   Integration Considerations

No GIS integration or inter-component integration problems have been identified for the Circulation Component. The data identified in Section 3.9 is required to support the Circulation Component algorithm.

4.0 DATABASE DEVELOPMENT AND MODULE TESTING

4.1 Database Development

The FKCCS is resulting in a spatially explicit information base from which analysis of the carrying capacity of the Florida Keys can be made for various land development scenarios. The manner in which this process is being managed is described in the following subsections.

4.1.1 Dataset Development for Integrated Water Module

CCAM is being built using ArcInfo 8.0's personal geodatabase as the mechanism to store and retrieve original and derived data from the model. A personal geodatabase is implemented as a Microsoft Access 2000 database from within ArcInfo 8.0. The benefits of using the personal geodatabase capabilities of ArcInfo are threefold:

- First, the data will be in one database as opposed to a series of directories housing coverages.

- Second, relational databases are becoming the standard within the GIS and information technology industries, and ESRI has embraced this trend.

- Third, addressing these data management issues now will further assist the long-term implementation of the CCAM and success of Florida Keys Carrying Capacity Study.

As a result, final datasets collected during this investigation are being integrated into the evolving CCAM geodatabase.

4.1.2 Documentation of Underlying Data

An extensive amount of information was acquired during the process of the ancillary investigations including documented telephone conversations, reports and articles, Internet downloads, prints of data, data files and GIS coverages. A data pedigree tag was attached to each of these items of information, which includes the following information:

- Document name,

- Source from which the document was acquired,

- Acquisition date,

- Component(s) for which the document contains relevant information, and

- Comments regarding the document and/or its data types.

Upon completion of the data pedigree, each item was logged into an Access database and subsequently filed.

4.2   Data Management Protocols

Data collected as part of the FKCCS are subjected to a deliberate inventory and management process. The contractor consulted with the FMRI during the initial phase of data acquisition to ensure close coordination throughout the process. For those data that are digital, in GIS format, or can be easily obtained, a data acquisition request was submitted to FMRI. However, the Contractor obtained data that are part of government reports, scientific publications, or those data that require specific water resource modeling insight.

Data that were received from FMRI were routed through the contractor's GIS staff. The data were inventoried and, in some cases, imported to the GIS. These data were then forwarded to the appropriate water resource engineer for further scrutiny. The Contractor's water resources staff managed the data until the GIS integration phase.

4.3   GIS Integration

The Water Resources and GIS staffs coordinated data distribution for integration into the evolving CCAM database. Data structure, format, and design were considered as part of this database integration activity. Limited geo-processing was conducted to facilitate the efficient storage of data as related tables in the database structure. For example, wastewater treatment attributes are now associated with the parcel dataset. In order to complete the assignment of wastewater treatment for each parcel, the water resource staff manipulated the parcel attributes in Microsoft Excel. Once complete, the GIS staff brought those data into the CCAM geodatabase and related them to the spatial component of the parcel dataset.

As another example, weather data were collected and reviewed in a spreadsheet format by water resource engineers. The GIS staff, after consulting the appropriate water resource engineer, integrated those data into the CCAM geodatabase and associated the data with the wastewater planning units. Lastly, data such as the wastesheds originated in GIS format and their integration into the CCAM geodatabase was a natural progression in the development of those data. GIS staff provided a water resource staff member with data and a brief training session to facilitate the digitizing of wastesheds using ArcView. These data were then reviewed and edited by GIS staff to check for basic topological and projection standards. A joint visual review of hardcopy maps was conducted as part of the final review prior to integrating these data into the CCAM geodatabase.

In addition to acquiring and managing the GIS data, the FKCCS is using Spatial Metadata Management System (SMMS) to document all data that are part of the CCAM. SMMS is specifically designed to manage metadata and comply with Federal Geographic Data Committee (FGDC) and State documentation standards. FMRI is providing the contractor with metadata for all data that they are acquiring for the FKCCS. The Contractor will generate metadata for those data that were collected as part of this investigation. For example, the University of Florida produced hardcopy reports and maps of boating anchorages throughout the Florida Keys. The Contractor converted these data to a digital GIS format. If those data become part of the CCAM

geodatabase, the Contractor will generate metadata for that information. Likewise, the Contractor will generate metadata for the delineated wastesheds.

These database development, management, and GIS integration activities assist in the development of the CCAM in at least two ways. First, the contractor has an understanding of the information and can access the data in an efficient manner to finalize the relationships between components of the water module and the integration of the water module into the entire CCAM. Second, these activities will facilitate the implementation of the final CCAM database.

4.4   Integrated Water Module Testing

Testing of the current formulation of the Integrated Water Module to make sure that it is functioning properly requires examination of the following aspects of the simulation process:

- Operational aspects of the CCAM automation related to the Integrated Water Module.

- Sensitivity of the Integrated Water Module to selected input values and constant values.

- Reasonableness of the simulation of existing conditions given an understanding of current conditions within the Florida Keys.

- Reasonableness of the Future Conditions Scenarios.

- Consideration of overall CCAM integration.

4.4.1   <u>Operational Aspects of CCAM Automation Related to the Module</u>

The first step in testing the Integrated Water Module is to check four computational aspects of the module programming within the framework of the overall CCAM:

- Checking that the inputs from other "upstream" modules are actually being provided to the Integrated Water Module, and that the inputs provided are in the proper format with respect to their alpha/numeric fields, decimal precision and units.

- Testing of the internal programming of the Integrated Water Module's nine components to make sure that it is functioning correctly should check three computational aspects of the module programming.

- Checking intra-component linkages in the Integrated Water Module to make sure that data is being properly passed between each of the nine components.

- Testing to verify that the outputs from the nine components of the Integrated Water Module are actually provided to the other "downstream" modules of the CCAM.

This initial testing process should assure that the Integrated Water Module and its internal components work as intended within the current module formulation, and also ensure that they communicate properly with the other upstream and downstream CCAM modules.

To this end, it is recommended that:

- A small test area within the Florida Keys be used as the basis of computational testing.

- An external set of manual computations be developed outside of CCAM to be used as the basis for comparison.

- A comparison be conducted between the external computations and CCAM's computations to validate CCAM's results and programming.

This process should provide the Government Study Team with confidence in the internal computational integrity of the Integrated Water Module, irrespective of the module's sensitivities or selected scenarios.

4.4.2   Sensitivity of the Module to Selected Input Values and Constants

Most models are tested in a sequential process of single variable manipulation to evaluate their sensitivity to specific inputs. The testing process generally involves:

- Identifying a list of model input variables and constants that are suspected to produce potentially large changes in simulated results for specific changes in inputs.

- Deciding what range of value deviation, commonly 50 percent and 200 percent of the normal value, should be used to test each suspected input constant or variable.

- Conducting individual simulation tests of altered values for each suspected input constant and input variable and then recording the resulting change in output values.

Examining which input variable and constants the model is sensitive to will provide insight that will be useful for

- Subsequent refinements in formulation, logic and input constants of the Integrated Water Module.

- Developing and evaluating the CCAM-simulated results of future development scenarios for the Florida Keys.

- Prioritizing potential management strategies and intervention concepts for possible implementation by Florida Keys communities.

This process should provide the Government Study Team with insight and understanding of potential limits with respect to selecting potential development scenarios for evaluation within the CCAM framework.

4.4.3   **Reasonableness of the Simulation of Existing Conditions**

The traditional testing strategy for a simulation model of this nature is to conduct a simulation of a recorded event using the observed ambient conditions and inputs to drive the model and then comparing the simulated outputs with observed field data. Unfortunately, no consistent set of data exists for a singular event that includes the ambient conditions at the onset of the event, the input data for all components of the Integrated Water Module, and corresponding field observations for all of the module's output. In fact, very little event-based calibration and verification data exists for any component of the module.

Consequently, this approach cannot be used to test the simulated outputs of the Integrated Water Module. The alternate approach to be used is to test the reasonableness of the Integrated Water Module's simulated outputs against either the limited amount of suitable field observations of representative events that normally occur in the Florida Keys or the Government Study Team's understanding of existing conditions within the Florida Keys.

4.4.4   **Reasonableness of the Future Conditions Scenarios**

Modeling experience has shown that virtually every model can be forced to provide unusual and unreasonable results if given inputs that either are atypical of the system that is being modeled or are outside normal conditions dictated by the underlying physical processes that govern the system. Clearly, it is essential that the testing process use realistic scenarios as a basis for testing the Integrated Water Module as well as the CCAM. To this end, the following concepts are suggested as a basis for developing scenarios to be evaluated in the Integrated Water Module:

- *Realistically Grounded Scenarios:* All scenarios should be reality-based and reflect potential development concepts that are likely to occur within the next 20 years within the Study Area (development of all ROGO SFR lots), as opposed to unlikely concepts such as extensive development of all properties with corresponding development of required infrastructure systems.

- *Definition of Land Use Spatial Impacts with Temporal Milestones:* Any policy decision within a scenario that causes land use modifications must be able to be defined in terms of parcel level impacts that can be converted to spatial changes occurring at fixed temporal times—or conversely at uniform rates over fixed intervals—in the Land Use Module, which provides the direct spatial and temporal data inputs to the Integrated Water Module.

- *Definition of Management Decisions for Selected Infrastructure System:* Any policy decision that is incorporated in a scenario that causes modifications of existing potable water, stormwater, or wastewater infrastructure systems must be able to be defined in terms of specific component modifications that can subsequently be translated into spatial changes occurring at fixed temporal

times-or conversely at uniform rates over fixed intervals-in the Land Use Module, or as modification to input variables to specific components of the Integrated Water Module.

- *Consistency with Component Formulations:* Each scenario that is developed for testing should be examined for conflicts with the physical processes being simulated, the segmentation of physical processes, the discretization of physical systems, and the enabling assumptions that were used in the formulation of the nine components of the Integrated Water Module.

- *Consistency with Previous Inputs:* Any scenario that is developed for testing should be consistent with the input provided by the Government Study Team in terms of their consolidated review comments and suggestions, other inputs from their panel of experts, and the National Academy of Science reviewers.

It is critically important that the initial scenarios that are developed for the purpose of testing the Integrated Water Module be based upon realistic expectations of future land use changes and utilizes a set of user choices that are within normal ranges. To this end, it is recommended that scenarios should developed for initial testing that:

- Match scale and complexity of the of the overall study objectives.

- Represent regional views of future development.

- Include both new and redevelopment of parcels.

- Include environmental restoration (un-development) concepts.

- Provide for reasonable seasonal variability in resident, seasonal visitor and day-tripper populations.

- Consider a limited number of options for providing on-site and localized wastewater treatment for new development and redevelopment.

- Limit options for conversion of existing "hot spot" and non-complying on-site wastewater systems to on-site technologies that provide higher treatment and lower concentration effluents.

- Provide number of options for providing on-site and localized stormwater management approaches for new development and redevelopment.

Once the initial testing is completed, a limited second set of scenarios should be developed and subsequently used for testing the Integrated Water Module, which are more complex in concept, represent a wider range of decisions, and more characteristic of local concerns. Complexities that should be considered in the second set of scenarios include:

- Island-by-island allocation of development to demonstrate that the Integrated Water Module can handle localized scenarios that are specific to just one or a few islands, if necessary.

- Management strategies that make adjustment for existing development through infrastructure retrofitting to provide structural intervention approaches.

- Include options for stormwater infrastructure retrofitting approaches for existing development through the use of BMPs that provide structural intervention.

- Consideration of options for existing on-site wastewater systems that actually comply with current treatment and effluent requirements to upgrade existing systems to on-site technologies that provide higher quality effluents.

- Include options for stormwater infrastructure retrofitting approaches for existing development through the use of BMPs that provide structural intervention.

- Provide for the conversion of existing on-site wastewater systems that actually comply with current treatment and effluent requirements, to better on-site or regional wastewater treatment systems that provide higher quality effluents.

The development of the initial and second set of scenarios should be conducted in a collaborative effort between the Client, the Contractor, and future CCAM users, preferably in a workshop format. This approach will facilitate a clear understanding by all participants and will also serve to fine tune the scenarios in a timely manner, which will facilitate the overall testing process.

4.4.5   Consideration of Overall CCAM Operations

Testing must also consider the following items with respect to the overall CCAM operation:

- *The GIS and hardware/software platform of the model:* The Draft CCAM was developed using hardware/software solutions that best match the currently defined needs of the identified users. Key feasibility questions were addressed and a workable hardware/software platform was established for the model.

- *The acquisition and assimilation of key datasets:* Key datasets for the model include land use and ownership, and seasonal population information. A preliminary assessment of data suitability was completed.

- *Limited computer programming to test for automation:* Computer code was developed to explore automation issues for the model. Automation tests were developed for portions of the terrestrial and stormwater modules.

5.0   SUPPLEMENTAL MODEL DEVELOPMENT

5.1   Additional Data Collection Recommendations

The ancillary investigations authorized in this investigation provided a substantial basis for understanding the physical processes in play in the Florida Keys, for reformulating the internal components of the Integrated Water Module, and for developing their supporting dataset. However, a limited amount of additional data is still needed to complete the development process for the Integrated Water Module. Specific areas still requiring additional data collection include:

- Planned capital investment projects and representative systems operating costs for the publicly owned components of the existing potable water infrastructure.

- Planned capital investment projects and representative systems operating costs for the publicly owned components of the existing stormwater infrastructure.

- Planned capital investment projects and representative systems operating costs for the publicly owned components of the existing wastewater infrastructure.

- Development of a list of intervention measures including their modelable consequences, in order to determine the level of detail that can be incorporated in the model and to ensure that both environmental and other effects are addressed.

5.2   Model Formulation Decisions

Two are several areas within the formulation of the Integrated Water Module that require the Government Study Team to make decisions on whether to include certain elements in the final module formulation. Specific decisions that need to be made include the following:

- Whether to include the pollutant loads associated with wetfall in the water quality computations for the immediate nearshore waters and marine waters, given the limited available data for wetfall in the Florida Keys.

- Whether to include the pollutant loads associated with dryfall deposition in the water quality computations for the immediate nearshore waters and marine waters, given the limited available data for dryfall deposition in the Florida Keys.

- Whether to assume pollutant load reduction rates for pollutants of interest to account for the treatment provided by vertical transport in the unsaturated zone underlying the developed islands, based upon documented values in other parts of the State for stormwater recharge to the water table and wastewater effluents from on-site treatment systems. Virtually no studies of treatment rates have been conducted in the Florida Keys.

- Whether to assume pollutant load reduction rates for pollutants of interest to account for the treatment provided by horizontal transport in the saturated zone underlying the developed islands, based upon documented values in other parts of the State for stormwater recharge to the water table, wastewater effluents from on-site treatment systems, and lateral movements of wastewater effluents discharged from disposal wells. Virtually no studies of treatment rates have been conducted in the Florida Keys.

- Whether to include the pollutant load associated with boating discharges in the water quality computations for the immediate nearshore waters and marine waters, given the limited available data for boating discharges in the Florida Keys.

5.3 Recommended Module Refinements

Three model refinements are recommended, based upon the ancillary investigations and reformulations that are not included in the Integrated Water Module as developed through DO 8.

Estimation of Groundwater Recharge Concentrations

Studies in the Florida Keys that document either the concentration of recharge entering the water table or the treatment provided by passing through the unsaturated zone have not been found during the ancillary investigations. Similar studies in other parts of the State provide information, but were not deemed to be suitable for the CCAM given the lack of soils and the unique subsurface conditions that exist in the Study Area. This information is important with respect to the final quality of groundwater discharged to the immediate nearshore waters. The proposed refinement involves establishing approximated pollutant reduction rates for the unsaturated zone based on a limited supplemental assessment using the following steps:

- Selection of two islands in the Upper Keys, underlain by Key Largo Limestone, and two islands in the Lower Keys that are underlain by Miami Limestone, for which ambient groundwater quality data is available.

- Use of the Integrated Water Module to predict the quality of the stormwater recharge and existing on-site treatment effluents.

- Comparison of the quality of the combined recharge/effluent with the ambient groundwater for parameters of interest.

- Selection of a set of pollutant load reduction rates to be used for assessing treatment provided by flow through the unsaturated zone prior to entering the water table.

This approach will bridge the gap between the current condition of no data, and the ideal condition of having detailed values provided by site-specific studies.

Estimation of Financial Requirements for Selected Keys Infrastructure Systems

The capital investment requirements and annual operations and maintenance costs of the improvements to public water supply, stormwater management and wastewater infrastructure system required by each scenario are an important consideration in assessing the viability and true carrying capacity status of each scenario. Assessment of potential costs to the private sector and private citizens is equally important. None of these considerations were included in the DO 8 scope of work.

The proposed refinement involves establishing the necessary algorithm elements for the Potable Water, Stormwater, and Wastewater and Boating Discharge Components to estimate the required financial costs associated with the capital investment requirements and annual operations and maintenance requirements of the public and private improvements to water supply, stormwater management and wastewater infrastructure systems. The new outputs from the Integrated Water Module will serve as direct inputs to the Fiscal Impacts Component of the Socio-Economic Module.

5.4   Final Observations

The Integrated Water Module, as currently formulated to use available data, can be used to evaluate relative impacts of development decisions made in the Keys. Limitations in data generally preclude the use of more precise modeling techniques that would require a significantly larger number of selectively structured synaptic data sets to cover the extensive spatial area of the Study Area. Consequently, this module uses standard analytical techniques, professional judgment, simple idealizations of relatively complex systems, a number of enabling assumptions and data collected from other investigations to produce a first-order estimate of flows and pollution loads generated by land-based activities in the Keys.

The Integrated Water Module requires a basic understanding of hydrology, hydraulics and water quality processes that are being simulated, combined with an appreciation of the existing utilities infrastructure and physical characteristics that are unique to the Keys, and an understanding of land use planning and regulatory processes.

It must be clearly recognized that while the stormwater and wastewater flows and pollutant loads are uncalibrated, due to the absence of suitable calibration/verification data, they are suitable for comparing one scenario to another scenario. The user must recognize that the Module's results are uncalibrated and can not be used to make inferences about resultant water quality concentrations or attainment of standards.

GLOSSARY

Algorithm: A procedure for solving a mathematical problem in a finite number of steps.

ArcInfo: A geographic information system created and sold by Environmental Systems Research Institute. This is the geographic information system software package being used in the Florida Keys Carrying Capacity Study.

Best Management Practices: Usually used in referring to stormwater or wastewater treatment practices, this is a set of practices or actions that represents the best available means of controlling flows or composition of discharge waters available for a particular land use or practice. It usually refers to non-structural low cost actions such as street sweeping, fertilizer application guidelines, or education programs.

Boating Discharge: Sanitary wastes generated on boats and discharged to the marine environment.

Carrying Capacity: The amount of use an area, resource, facility or system can sustain without deterioration of its quality.

Carrying Capacity Analysis Model: A geographic information system-based model developed to determine the ability of the Florida Keys ecosystem to withstand all impacts of additional land development activities.

Cesspit: A method of collecting sanitary wastes, usually from single-family residential units, similar to a septic tank, but with no finger system or leach field, and little to no treatment capability.

Coefficient: A numerical value within a formula or computation that expresses a relationship and is applied in a mathematical function.

Component: A discrete subset of inputs, calculations, and outputs of a module. One or more components can create a CCAM module. Please see module and element.

Comprehensive Plan: Refers to a plan, or any portion thereof, as adopted by a local government, to manage the quantity, type, cost, location, timing, and quality of development and redevelopment in the community.

Conservative: When used with regulatory standards or describing criteria, a term that refers to the most strict standard or the condition implying the greatest degree of a safety or buffer level.

Contaminant: A substance (in water for this study) that can have harmful properties and is not naturally occurring or occurs above natural background levels. For the Marine and Integrated Water Modules, this term refers only to the metals cadmium, copper, lead, and zinc.

Coverage: A map layer or digital version of a map in the GIS system, usually associated with one type of feature, such as Land Use.

Degradation: The decline in the quality and/or ecological functions of an area.

Density: The average number of dwelling units allocated per gross acre of land. The density ranges used in the model are adapted from FLUCCS as well as from the Monroe County Comprehensive Plan.

Development: The process of converting the land cover of a parcel to a different land cover of a higher use and/or intensity.

Discharge: In this study, a term referring to the amount and location of water leaving a wastewater treatment system of stormwater leaving a treatment system or unit of land, usually measured at a specific point (Discharge Point).

Dwelling Unit: One or more rooms physically arranged to create a housekeeping establishment for occupancy by one family only.

Element: An algorithm, coefficient, or data table that is used within a component. One or more elements can create a component. Please see module and component.

Eutrophication: The process of increasing productivity in a water body, eventually leading to senescence and decline of the ecosystem.

Event Mean Concentration: A measure of the concentration of a material or contaminant in stormwater for a specific rainfall event, expressed as an average over time based on the mass concentration and volume and duration of flow over time.

Extent: The scope of an issue, or the range or areal extent of an activity or impact.

Field: A term used to define the portion of a database that contains all the data entries for a specified item or parameter, such as all "Land Use Type" entries; analogous to a column in a data table.

Goal: Refers to a concise but general statement of a community's aspirations in addressing a problem or an opportunity, in terms of a desired state or process toward which implementation programs are oriented.

Grid: A raster-based type of geographic data set for use with the geographic information system, based on x,y values. This is an alternative method of presenting and analyzing data to the arc-based polygon methods in a geographic information system.

Grid Cell: In a geographic information system, the basic spatial element of a grid, representing a portion of the earth, in a grid-based data set. A group of cells forms a grid. Each grid cell has a value corresponding to the characteristics at that site, such as habitat type.

Groundwater: The volume of water naturally occurring under the land surface.

Groundwater Recharge: The movement of surface water into the ground through percolation or direct means, eventually reaching the water table and replenishing the groundwater.

Household: A household includes all the persons who are current residents of a housing unit. The occupants may be a single-family, one person living alone, two or more families living together, or a group of related or unrelated persons who share living arrangements.

Housing Unit: A house, an apartment, a mobile home or trailer, a group of rooms or a single room occupied as separate living quarters or, if vacant, intended for occupancy as separate living quarters.

Immediate Nearshore Waters: The waters that are within 100 meters of the shore around the more developed Keys, which exhibit specific characteristics.

Infrastructure: The basic facilities and equipment necessary for the effective functioning of the Town, such as the means of providing water service, sewage disposal, electric and gas connections, and the street network. For the Carrying Capacity Analysis Model, adequate data is currently available only for water service and sewage.

Input: Data that are entered into the Carrying Capacity Analysis Model.

Integration: The unification of individual modules within the CCAM to create a holistic modeling approach, results, and tool.

Land Use: A description and classification of how land is occupied or utilized, e.g., residential, office, parks, industrial, commercial, etc.

Location: In the Carrying Capacity Analysis Model Scenario Generator, this refers to an input condition specifying a geographic area of the Study Area in which a condition is to be applied.

Look-Up Table: A special tabular data file for the geographic information system containing additional attributes for features stored in an associated feature attribute table, or a table in which numeric item values are classified into categories.

Lot: A parcel of land occupied or intended for occupancy by an individual use, including a principal structure and any ancillary/accessory structures.

Marine Environment: The salt and brackish waters surrounding the Florida Keys and the organisms and communities within these waters, usually extending shoreward to the mean high tide line.

Methodology: A set of rules and procedures for a given module.

Mixed Use: Refers to development projects or zoning classifications that provide for more than one use or purpose within a shared building or development area. Mixed use allows the integration of commercial, retail, office, medium- to high-density housing, and in some cases light industrial uses. These uses can be integrated either horizontally or vertically in a single building or structure.

Model: A system of data, assumptions, and calculations used to represent and visualize reality. Please see Carrying Capacity Analysis Model.

Module: One of several major parts of the Carrying Capacity Analysis Model. A module is comprised of components. Please see component and element.

New Development: Development that occurs in vacant or unoccupied land, as opposed to a change within already developed land.

Nutrient: A constituent in water that is necessary for or promotes growth of plants.

Objective: A clear and specific statement of planned results, derived from a goal, to be achieved within a stated time period.

On-Site Treatment System: A wastewater treatment system which is on the same lot or parcel of land in which the wastes are generated.

Open Space: Land devoted to uses characterized by vegetative cover or water bodies, such as agricultural uses, pastures, meadows, parks, recreational areas, lawns, gardens, cemeteries, ponds, streams, etc.

Output: A result that is either used as an input to another CCAM module or as an end-point in an analysis.

Parameter: A quantity or constant whose value varies with the circumstances of its application or is used as a referent for determining other variables.

Parcel: Any quantity of land and water capable of being described with such definiteness that its location and boundaries may be established and identified.

Planning Unit: See Wastewater Planning Unit.

Policy: The specific approach through which objectives are achieved.

Polygon: A multisided feature representing an area on a map, with the boundary of the polygon defined by arcs.

Population, Seasonal: That segment of the population that stays in the Keys for 30-180 days usually during the summer or winter "seasons."

Potable Water: Water that is suitable and approved for human consumption (= drinking water).

Potable Water Consumption: The use or rate of water use.

Pre-processing: Preliminary data manipulation prior to Carrying Capacity Analysis Model runs.

Qualitative: A number that is not based on a discrete number or unit of measure. This is often an estimate and may be expressed on a relative scale of magnitude.

Quantitative: A measurement that is based on a number that has known, discrete units of measure.

Recharge: The movement of water through the ground and the groundwater.

Redevelopment: Refers to public and/or private investment made to re-create the fabric of an area that is suffering from physical, social or economic problems related to the age, type, and condition of existing development. Redevelopment can help to meet market needs for residential and/or commercial development in older parts of the Town.

Restoration: The conversion of non-natural lands into natural areas.

Retrofit: The process of changing or adding facilities to an already constructed facility or existing land use development. For the Carrying Capacity Analysis Model, this usually refers to wastewater or stormwater treatment facilities.

Runoff: Rain water that moves across the land surface to exit a property or area (= stormwater runoff).

Scenario: A change in land use described by the location, type, extent, and configuration of the land use change. Changes in land use may include new development, redevelopment, and restoration.

Seagrass: A type of submerged vascular plant (as distinguished from algae) that can form dense stands or beds in shallow marine water that are important marine habitats and energy sources for marine animals. Turtle grass is the main seagrass species in the Keys.

Seasonal Population: See Population, Seasonal.

Solid Waste: Refers to garbage, refuse, sludges, and other discarded materials.

Stormwater Management: Refers to the natural and/or constructed features of a property which function to treat, collect, convey, channel, hold, inhibit, or divert the movement of surface water.

Study Area: The area within the statutorily defined limits of the FKCCS. This includes the non-mainland portion of Monroe County to the outer limits of the Florida Keys National Marine Sanctuary excluding those waters surrounding the Marquesas and Dry Tortugas. For traffic and evacuation study purposes, portions of U.S. 1 on the mainland are included.

Suitability: The inherent or regulated capability of a parcel to support a particular land use. Suitability analysis is employed in the CCAM to determine the fitness of a given tract of land for a specific use. In this case, the degree of suitability is assessed based on the following factors, for which data are currently available: (a) parcel size; (b) subdivision status (platted vs. non-platted); (c) type of land cover; (d) flood zone classification; (e) accessibility to infrastructure (specifically sewer and water); (f) location with respect to areas of critical habitat (as defined in the *Monroe County Comprehensive Plan*).

Type (Residential): Characterization of housing choices according to occupancy (single-family, multi-family) or construction (detached, attached).

Use: The specific activity or function for which land, a building, or a structure is designated, arranged, occupied or maintained.

Wasteshed: The land area above a discharge point that includes all sources of wastewater discharging to that point. In this study, wastesheds have been defined with the same boundaries as watersheds.

Wastewater: Waste that is treated through some type of sanitary treatment system.

Wastewater Planning Unit: One of twenty-eight areas throughout the Florida Keys that were used in the Monroe County Sanitary Wastewater Master Plan analysis and documentation.

Wastewater Treatment System: A facility for processing sanitary wastewater by removing contaminants, nutrients, and pathogens. For example, central treatment systems, septic tanks, and cesspits.

Water Clarity: A measure of the transparency of water and a measure of the depth to which sunlight can penetrate water. Depth of sunlight penetration is a key factor in the distribution of seagrasses.

Watershed: A catchment area that is otherwise draining to a watercourse or contributing flow to a body of water.

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APPENDIX A

FLORIDA KEYS AQUEDUCT AUTHORITY
WATER SOLD (Gallons)

		1997 OCT	NOV	DEC	1998 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Area 1	KEY WEST												
	Residential	49,821,100	59,450,200	47,395,200	59,897,700	57,133,300	51,861,300	60,116,800	57,948,700	60,647,100	61,407,500	57,199,900	54,296,200
	Commercial	38,710,400	47,893,200	38,593,300	48,905,200	43,104,900	43,923,400	49,684,400	49,042,200	46,584,400	51,445,100	50,004,300	44,469,300
	Government	1,527,600	1,992,000	1,422,000	1,899,600	1,675,500	1,422,200	1,644,600	2,015,600	1,785,100	2,497,900	1,428,500	2,053,200
	Municipal	2,886,500	3,285,800	2,512,000	3,637,300	1,273,700	2,093,900	3,313,600	3,859,800	3,353,900	3,612,600	3,408,000	4,062,200
	U.S. Navy	22,169,000	25,856,000	24,373,000	24,215,000	25,166,000	24,809,000	27,091,000	32,751,000	38,745,000	36,524,000	28,738,000	28,469,000
	Sub-total	115,094,600	138,477,200	114,295,500	138,554,800	128,353,400	124,109,800	141,852,400	145,617,300	151,115,500	155,487,100	140,778,700	133,389,900
Area 2	STOCK ISLAND/ LITTLE TORCH												
	Residential	25,611,000	32,174,500	28,662,800	34,958,800	32,027,500	29,933,300	35,844,500	39,327,100	37,978,100	40,994,600	36,265,000	31,798,700
	Commercial	9,698,000	12,273,000	11,673,300	13,988,500	13,820,700	13,319,900	15,321,000	14,549,400	13,764,700	13,437,500	13,187,800	11,917,100
	Government	2,236,800	2,680,400	2,481,900	2,243,300	2,569,100	2,207,800	2,356,700	2,729,200	3,015,200	3,169,500	3,228,900	3,103,900
	Municipal	281,200	295,800	364,000	333,500	378,800	325,000	371,700	466,600	496,200	507,100	559,400	527,800
	U.S. Navy	1,813,000	2,082,000	2,028,000	1,362,000	1,767,000	1,550,000	1,893,000	2,209,000	2,328,000	4,747,000	448,000	2,166,000
	Sub-total	39,640,000	49,505,700	45,210,000	52,896,100	50,563,100	47,336,000	55,786,900	59,281,300	57,582,200	62,875,700	53,689,100	49,413,500
Area 3	BIG PINE/ MARATHON												
	Residential	30,637,400	39,752,100	30,508,200	44,303,400	36,849,000	37,209,100	46,163,000	47,158,500	46,406,600	46,951,900	46,509,800	39,566,400
	Commercial	19,857,000	26,148,500	22,059,600	31,403,100	27,019,200	27,342,100	30,040,100	27,317,600	27,961,200	28,667,100	31,637,800	27,017,700
	Government	1,663,900	2,295,000	1,696,300	2,302,100	2,054,000	2,089,900	2,606,900	3,105,200	3,380,800	3,096,100	3,072,100	2,648,400
	Municipal	0	0	0	0	0	0	0	0	0	0	0	0
	U.S. Navy	139,000	136,000	148,000	140,000	159,000	121,000	124,000	120,000	157,000	221,000	123,000	101,000
	Sub-total	52,297,300	68,331,600	54,412,100	78,148,600	66,081,200	66,762,100	78,934,000	77,701,300	77,905,600	78,936,100	81,342,700	69,333,500
Area 4	ISLAMORADA												
	Residential	17,214,900	23,947,000	19,992,000	27,470,700	21,813,300	23,654,100	27,873,600	31,104,100	32,265,800	36,970,200	28,809,100	27,719,300
	Commercial	14,708,600	19,064,700	15,104,400	21,238,000	16,706,900	19,326,900	21,495,600	20,518,500	22,641,300	24,002,700	21,587,200	19,015,100
	Government	855,800	952,600	712,000	895,600	759,900	881,800	1,019,100	1,177,700	1,355,500	1,639,200	1,258,500	1,125,500
	Municipal	0	0	0	0	0	0	0	0	0	0	0	0
	U.S. Navy	79,000	78,000	87,000	103,000	96,000	112,000	170,000	280,000	156,000	129,000	106,000	104,000
	Sub-total	32,858,300	44,042,300	35,895,400	49,707,300	39,376,100	43,974,800	50,558,300	53,080,300	56,418,600	62,741,100	51,760,800	47,963,900
Area 5	TAVERNIER/ KEY LARGO												
	Residential	42,129,300	53,531,200	46,185,000	59,455,800	47,423,800	48,284,300	57,409,600	63,847,300	65,977,600	65,962,600	63,299,500	59,234,900
	Commercial	22,664,200	31,020,800	25,450,300	32,785,100	26,481,700	27,537,500	31,589,600	33,249,400	33,992,600	33,914,200	33,529,600	30,307,900
	Government	975,700	1,146,500	697,500	856,600	669,900	946,100	1,815,600	1,661,400	1,702,600	1,859,900	1,656,600	1,364,400
	Municipal	0	0	0	0	0	0	0	0	0	0	0	0
	U.S. Navy	0	0	0	0	0	0	0	0	0	0	0	0
	Sub-total	65,769,200	85,698,500	72,332,800	93,098,500	74,575,400	76,767,900	90,814,800	98,758,100	101,672,700	101,758,700	98,485,900	90,907,200
	Grand Total	305,659,400	386,055,300	322,145,800	412,395,300	358,949,200	358,950,600	417,946,400	434,438,300	444,594,500	461,796,700	426,057,200	391,008,000

	1998 OCT	NOV	DEC	1999 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Area 1 KEY WEST												
Residential	48,419,600	56,432,200	53,975,200	61,979,200	57,551,600	56,176,700	68,197,500	65,701,900	60,617,800	58,066,900	59,482,200	53,249,600
Commercial	35,052,300	45,423,900	43,011,300	48,535,900	45,089,900	50,332,200	58,027,400	55,487,100	51,487,700	50,802,100	50,628,500	47,025,200
Government	1,193,200	1,566,300	1,522,300	1,308,300	1,368,300	1,628,900	1,824,700	1,922,400	1,849,000	1,418,700	1,477,300	1,772,700
Municipal	2,411,500	2,638,800	2,805,900	3,101,600	3,065,600	2,846,100	3,178,000	3,459,600	2,766,600	2,127,000	2,637,200	2,392,800
U.S. Navy	21,715,000	29,051,000	26,996,000	29,255,000	30,661,000	27,788,000	36,841,000	36,873,000	34,247,000	26,599,000	29,631,000	24,999,000
Sub-total	108,791,600	135,112,200	128,310,700	144,180,000	137,736,400	138,771,900	168,068,600	163,444,000	150,968,100	139,013,700	143,856,200	129,439,300
Area 2 STOCK ISLAND/ LITTLE TORCH												
Residential	40,188,100	34,646,600	32,445,300	36,000,000	36,078,700	36,238,600	47,740,300	44,305,400	36,535,300	33,560,600	34,939,500	32,605,500
Commercial	11,703,600	26,018,500	11,162,400	10,005,600	14,283,100	12,439,900	15,284,800	13,424,000	12,164,600	11,692,300	12,197,300	12,684,400
Government	2,463,900	2,812,500	2,929,400	3,130,800	3,019,300	2,396,600	2,985,700	3,092,300	2,847,700	2,366,800	2,872,000	2,638,700
Municipal	509,300	582,100	497,800	475,500	612,600	472,300	368,900	495,200	822,100	990,000	762,700	338,700
U.S. Navy	2,206,000	1,913,000	1,636,000	1,692,000	2,114,000	2,041,000	3,105,000	3,148,000	3,210,000	2,064,000	2,745,000	2,400,000
Sub-total	57,070,900	65,972,700	48,670,900	51,303,900	56,107,700	53,588,400	69,484,700	64,464,900	55,379,700	50,673,700	53,516,500	50,667,300
Area 3 BIG PINE/ MARATHON												
Residential	44,316,800	36,848,500	37,841,100	48,636,100	42,864,700	45,957,500	57,550,400	55,032,400	45,299,200	41,920,500	48,818,900	41,094,800
Commercial	25,336,400	22,818,400	23,713,700	31,230,600	28,558,800	29,287,300	33,650,800	31,959,700	27,247,600	26,378,400	31,777,400	27,075,300
Government	2,242,900	1,919,800	2,302,700	2,535,600	2,242,900	2,327,700	3,502,600	3,940,600	3,166,100	2,523,000	2,904,100	2,350,600
Municipal	0	0	0	0	0	0	0	0	0	0	0	0
U.S. Navy	75,000	82,000	68,000	67,000	85,000	89,000	110,000	169,000	92,000	83,000	156,000	72,000
Sub-total	71,971,100	61,668,700	63,925,500	82,469,300	73,751,400	77,661,500	94,813,800	91,101,700	75,804,900	70,904,900	83,656,400	70,592,700
Area 4 ISLAMORADA												
Residential	28,968,000	25,928,400	23,352,600	28,792,800	25,573,500	30,107,600	37,237,500	35,108,500	32,474,000	29,244,600	30,865,400	27,311,300
Commercial	18,205,000	16,211,300	17,370,200	22,204,100	20,364,400	22,558,500	25,395,500	22,059,500	21,095,800	20,599,400	21,640,100	18,205,600
Government	1,064,900	1,096,700	1,021,800	1,161,000	943,700	949,800	1,392,900	1,136,300	1,213,600	1,149,100	1,613,200	1,328,100
Municipal	0	0	0	0	0	0	0	0	0	0	0	0
U.S. Navy	115,000	78,000	76,000	73,000	81,000	86,000	196,000	203,000	156,000	151,000	95,000	80,000
Sub-total	48,352,900	43,314,400	41,820,600	52,230,900	46,962,600	53,703,900	64,221,900	58,507,300	54,939,400	51,144,100	54,213,700	46,925,200
Area 5 TAVERNIER/ KEY LARGO												
Residential	58,811,900	51,661,400	52,473,200	64,226,800	55,716,700	62,262,400	76,970,600	74,844,200	64,693,900	56,133,100	60,771,200	58,029,800
Commercial	29,409,900	27,715,100	27,380,000	34,074,800	29,243,400	32,733,500	40,350,700	39,136,100	34,481,100	29,529,200	32,600,300	30,777,800
Government	1,208,700	1,516,900	1,037,400	1,415,700	1,289,300	1,271,300	1,842,000	1,929,200	2,256,900	1,895,200	1,402,000	1,775,700
Municipal	0	0	0	0	0	0	0	0	0	0	0	0
U.S. Navy	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total	89,430,500	80,893,400	80,890,600	99,717,300	86,249,400	96,267,200	119,163,300	115,909,500	101,431,900	87,557,500	94,773,500	90,583,300
Grand Tot:	375,617,000	386,961,400	363,618,300	429,901,400	400,807,500	419,992,900	515,752,300	493,427,400	438,524,000	399,293,900	430,016,300	388,407,800

FLORIDA KEYS AQUEDUCT AUTHORITY
WATER SOLD (Gallons)

	1999 OCT	NOV	DEC	2000 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Area 1 KEY WEST												
Residential	52,917,600	53,239,900	58,730,000	64,109,000	61,807,100	62,416,700	67,921,800	64,140,400	62,857,800	63,700,400	62,578,200	56,393,500
Commercial	38,738,500	43,082,800	48,017,700	51,907,000	50,261,400	49,890,500	58,770,600	52,998,800	52,808,100	53,003,400	54,069,400	47,817,800
Government	1,662,800	1,413,900	2,020,900	1,815,700	1,706,400	2,004,500	2,346,400	1,852,300	1,919,100	2,212,000	2,360,500	1,913,800
Municipal	1,932,800	1,801,600	6,132,700	3,751,100	2,779,700	3,748,400	4,291,300	3,655,900	3,152,400	3,534,300	3,810,000	2,729,100
U.S. Navy	25,330,000	22,220,000	22,614,000	25,371,000	28,075,000	28,147,000	31,205,000	34,080,000	34,240,000	28,500,000	32,852,800	26,735,000
Sub-total	120,581,700	121,758,200	137,515,300	146,953,800	144,629,600	146,007,100	164,535,100	156,727,400	154,987,400	150,950,100	155,490,900	135,589,200
Area 2 STOCK ISLAND/ LITTLE TORCH												
Residential	30,381,300	28,237,000	33,054,200	41,577,500	42,819,800	36,025,800	46,401,800	38,171,700	43,382,300	37,783,600	35,486,900	35,368,200
Commercial	12,703,700	10,640,600	11,359,300	14,763,800	15,454,000	12,855,500	14,880,500	12,376,400	13,328,200	13,088,600	13,015,400	13,137,200
Government	2,910,000	2,829,200	3,220,900	3,227,800	3,827,900	3,261,100	3,534,400	2,999,000	(6,000)	2,899,500	2,528,600	3,237,400
Municipal	348,900	373,000	224,200	545,100	744,400	270,800	482,500	333,500	382,800	547,100	287,500	364,300
U.S. Navy	2,466,000	2,291,000	3,137,000	3,237,000	4,840,000	4,028,000	4,208,000	3,716,000	3,908,000	2,539,000	3,234,000	2,373,000
Sub-total	48,809,900	44,370,800	50,995,600	63,351,200	67,486,100	56,441,200	69,507,200	57,596,600	60,995,300	56,857,800	54,552,400	54,480,100
Area 3 BIG PINE/ MARATHON												
Residential	33,450,100	34,818,200	42,399,600	44,997,000	49,434,400	47,736,200	57,277,500	46,640,500	53,868,100	48,647,700	48,915,000	44,687,900
Commercial	21,653,600	22,192,500	25,822,000	26,972,400	32,081,400	31,340,500	35,215,500	29,729,000	33,008,300	32,037,100	33,591,100	27,096,500
Government	2,499,000	2,130,400	2,428,800	1,933,000	2,349,700	2,313,800	2,727,600	2,552,600	3,190,200	2,796,600	3,112,800	2,962,600
Municipal	0	0	0	0	0	0	0	0	0	0	0	0
U.S. Navy	97,000	70,000	87,000	87,000	104,000	109,000	96,000	96,000	111,000	67,000	81,000	65,000
Sub-total	57,699,700	59,211,100	70,737,400	73,989,400	83,969,500	81,499,500	95,316,600	79,018,100	90,177,800	83,548,400	85,699,900	74,812,000
Area 4 ISLAMORADA												
Residential	21,848,800	21,466,900	28,494,700	31,675,100	30,217,600	33,434,100	37,155,800	33,158,000	39,981,400	33,204,100	33,335,700	33,478,400
Commercial	13,853,400	13,508,100	15,752,300	19,097,800	18,173,000	21,187,100	22,557,100	20,309,200	22,715,200	23,194,300	21,192,600	20,552,400
Government	1,316,400	1,116,700	1,575,900	1,533,800	1,434,000	1,311,400	1,491,500	1,302,400	1,343,700	1,333,100	1,711,400	1,192,300
Municipal	0	0	0	0	0	0	0	0	0	0	0	0
U.S. Navy	69,000	64,000	146,000	107,000	88,000	159,000	126,000	85,000	121,000	126,000	103,000	84,000
Sub-total	37,087,600	36,155,700	45,968,900	52,413,700	49,912,600	56,091,600	61,330,400	54,855,600	64,161,300	57,857,500	56,342,700	55,307,100
Area 5 TAVERNIER/ KEY LARGO												
Residential	49,237,600	49,803,000	58,680,600	69,845,200	63,302,700	64,731,100	74,843,600	63,669,800	74,545,700	67,400,400	63,678,000	66,202,500
Commercial	25,928,700	25,660,000	29,473,500	36,001,800	31,963,600	36,627,300	40,452,500	34,241,100	37,442,100	36,549,300	35,951,300	33,350,300
Government	1,206,300	1,454,200	2,385,200	2,513,400	2,306,400	2,710,900	3,124,300	2,998,800	3,714,300	3,301,400	3,163,300	3,264,800
Municipal	0	0	0	0	0	0	0	0	0	0	0	0
U.S. Navy	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total	76,372,600	76,917,200	90,539,300	108,360,400	97,572,700	104,069,300	118,420,400	100,909,700	115,702,100	107,251,100	102,792,600	102,817,600
Grand Total	340,551,500	338,413,000	395,756,500	445,068,500	443,570,500	444,108,700	509,109,700	449,107,400	486,023,700	456,464,900	454,878,500	423,006,000

APPENDIX B

LIST OF ACRONYMS

ACSC	Area of Critical State Concern
ADCIRC	Advanced Three-Dimensional Circulation Model
ADID	Advanced Identification of Wetlands
AGR	Agriculture (land use)
ArcIMS	Arc Internet Map Server
ATU	Aerated Treatment Units
BAT	Best Available Technology
BEBR	Bureau of Economic and Business Research
BMP	Best Management Practices
BOD	Biological Oxygen Demand
BPK	Big Pine Key
CARL	Conservation and Recreational Lands
CCAM	Carrying Capacity Analysis Model
CCI	Competitive Commerce Index
Cd	Cadmium
CDM	Camp, Dresser, & McKee
CFBCM	Corps Florida Bay Circulation Model
CMC	Criterion Maximum Concentration
COD	Chemical Oxygen Demand
COM	Component Object Modeling
CPUE	Catch Per Unit Effort

Cu	Copper
DCA	Department of Community Affairs (Florida)
DCIA	Directly Converted Impervious Area
DEP	Department of Environmental Protection (Florida)
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DOQQ	Digital Orthophoto Quarter Quadrangle
DOT	Department of Transportation (Florida)
DRI	Development of Regional Impact
DU	Dwelling Unit
DXF	Digital Exchange File
EAR	Evaluation Appraisal Report
EDU	Equivalent Dwelling Unit
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
ESI	Environmental Sensitivity Index
FAC	Florida Administrative Code
FAR	Floor Area Ratio
FCT	Florida Communities Trust
FDOT	Florida Department of Transportation
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
FIU	Florida International University
FKAA	Florida Keys Aqueduct Authority
FKCCS	Florida Keys Carrying Capacity Study

FKEC	Florida Keys Electric Co-Op
FKNMS	Florida Keys National Marine Sanctuary
FLUCCS	Florida Land Use, Cover, and Forms Classification System
FLUM	Future Land Use Map
FMRI	Florida Marine Research Institute
FRT	Florida Reef Tract
FSC	Florida State Criterion
GFA	Gross Floor Area
GIS	Geographic Information Systems
GUI	Graphical User Interface
HCP	Habitat Conservation Plan
HDR	High Density Residential (land use)
IAV	Impact Assessment Variable
IDW	Inverse Distance Weighted
IND	Industrial (land use)
IP	Impact Probability
IS	Improved Subdivision
IT	Information Technology
ITE	Institute of Transportation Engineers
KCB	Key Colony Beach
LDR	Land Development Regulations
LDR	Low-Density Residential (land use)
LRP	Long Range Transportation Plan
MC	Monroe County
MCPD	Monroe County Planning Department

MCRT	Mean Cell Residence Time
MDR	Medium Density Residential (land use)
Mg	Magnesium
mg	milligram
mg/l	milligram per liter
mgd	Millions of Gallons per Day
MM	Mile Marker
MOU	Memorandum of Understanding
MPO	Municipal Planning Organization
MRFSS	Marine Recreational Fisheries Statistical Survey
MS4	Municipal Separate Storm Sewer System
N	Nitrogen
NO$_X$	Total Kjeldahl Nitrogen
NO$_2$	Nitrite
NO$_3$	Nitrate
NPSLAM	Non-Point Source Loading Assessment Model
O&M	Operation & Maintenance
OPEN	Open Space (land use)
OW	Open Water (land use)
OWNRS	On-site Wastewater Nutrient Reduction System
P	Phosphorous
PAED	Planning Area Enumeration District
PAR	Photosynthetically Active Radiation
Pb	Lead
PC	Property Code

PIIP	Public Involvement and Information Plan
PPH	Persons Per Household
PUV	Private, Upland, Vacant (area)
RD	Road (land use)
RDI	Relative Degradation Index
RFQ	Request for Quote
RHDI	Relative Habitat Degradation Index
ROGO	Rate of Growth Ordinance
RPT	Routine Planning Tool
RV	Recreational Vehicle
SFRPC	South Florida Regional Planning Council
SFWMD	South Florida Water Management District
SOD	Sediment Oxygen Demand
SRP	Soluble Reactive Phosphorous
Std. Dev.	Standard Deviation
TDP	Total Dissolved Phosphorous
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous
TRE	Transferable ROGO Exemption
TSS	Total Suspended Solids
UNA	User Needs Assessment
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency

USFWS	United States Fish and Wildlife Service
VBA	Visual Basic for Applications
µg	Microgram
WES	Waterways Experiment Station
WL	Wetlands (land use)
WQPP	Water Quality Protection Program
WW	Wastewater
Zn	Zinc